Canada

Ontario

FUEL CELLS WORKSHOP PROCEEDINGS

POTENTIAL OPPORTUNITES IN CANADA

APRIL 28, 1988

SKYLINE HOTEL, TORONTO

FOR FURTHER INFORMATION:

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Énergie, Mines et Ressources Canada
L'Hon. Marcel Masse, Ministre

Energy, Mines and Resources Canada
Hon. Marcel Masse, Minister

Ontario
Ministry of Energy
Honourable Robert C. Wong
Minister

Ministère de L'Energie
L'honorable Robert C. Wong
Ministre

FUEL CELLS

POTENTIAL OPPORTUNITIES

IN CANADA

The workshop is intended to inform Canadian industry about the current status, applications in industry and potential opportunities for fuel cell technology.

Recognized experts from U.S. and Canada will discuss technology applications emerging in North America and other countries, as well as discussions of the advantages and disadvantages of fuel cells. Case histories from current users of the technology will be presented. The day will conclude with an open panel discussion.

PERSPECTIVES D'AVENIR DES PILES À COMBUSTIBLE AU CANADA

L'atelier vise à informer l'industrie canadienne de la situation actuelle et des applications industrielles des piles à combustible et de leurs perspectives d'avenir.

Des experts américains et canadiens renommés traiteront des applications technologiques qui voient le jour en Amérique du Nord et à l'étranger, de même que des advantages et des inconvénients des piles à combustible. On parlera aussi de l'expérience des usagers actuels de cette technologie. Une discussion libre clôturera cette journée.

AGENDA

8:30 **REGISTRATION & COFFEE**

9:00 **MORNING SESSION**

Chairperson: Mr. Nick Markettos
Ontario Ministry of Energy

OPENING REMARKS

Mr. Bob Greven
Ontario Ministry of Energy

Dr. Fred Nemeth
Energy, Mines & Resources Canada

OVERVIEW

Large Scale Fuel Cells
Mr. Ed Gillis
Electric Power Research Institute
Palo Alto, California

Small Scale Fuel Cells
Mr. S. Abens
Energy Research Corporation
Danbury, Connecticut

10:10 **COFFEE**

10:40 **APPLICATIONS**

Gas Utility Viewpoint
Mr. Randy Petri
Institute of Gas Technology
Chicago, Illinois

Electrical Utility Viewpoint
Mr. Blair Seckington
Ontario Hydro
Toronto, Ontario

Industrial User Viewpoint
Mr. Frank Spillers
Industrial Fuel Cell Association
Washington, D.C.

11:40 **IMPEDIMENTS**

Technical
Dr. Halina Wroblowa
Ford Motor Company
Dearborn, Michigan

Commercialization
Mr. Paul Howard
Ballard Technologies Inc.
North Vancouver, B.C.

12:15 **LUNCH**

Keynote Address
Status, Future & Strategic
Applications of Fuel Cells
Dr. John Appleby
Texas A & M University
College Station, Texas

2:00 **AFTERNOON SESSION**

Chairperson: Dr. Fred Nemeth
Energy, Mines & Resources Canada

CANADIAN EXPERIENCE AND OPPORTUNITIES

Dr. M.M. Papic
B.C. Hydro
Surrey, British Columbia

Dr. Guy Belanger
Hydro Quebec
Varennes, Quebec

Mr. Gerald Crawford
Crawford and Associates
Mississauga, Ontario

3:00 **COFFEE**

3:15 **WORK SESSION: WHAT'S NEXT?**

Moderator: Mr. Jack Klieb
Ontario Ministry of Energy

Panel Members
. Mr. Joe Zanic, Dow Chemicals
. Mr. Blair Seckington, Ontario Hydro
. Mr. Dave Mcleod, Ballard Technologies Ltd.
. Mr. Richard Champagne, Hydrogen Industry Cncl
. Mr. Bill Podolny, International Fuel Cells

SYNOPSIS

Dr. Charles Ward
Centre for Hydrogen &
Electrochemical Systems
University of Toronto
Toronto, Ontario

GOOD MORNING LADIES AND GENTLEMEN

ON BEHALF OF THE HONOURABLE ROBERT C. WONG, MINISTER, AND THE STAFF OF THE ONTARIO MINISTRY OF ENERGY, I SHOULD LIKE TO WELCOME YOU TO THIS WORKSHOP DISCUSSING THE OPPORTUNITIES (AND PROBLEMS) RELATED TO THE DEVELOPMENT AND COMMERCIALIZATION OF FUEL CELLS.

SOME TIME AGO, WE IDENTIFIED FUEL CELLS AS AN EMERGING ENERGY TECHNOLOGY THAT COULD BE OF STRATEGIC IMPORTANCE TO ONTARIO.

THERE ARE AT LEAST FIVE OR SIX DIFFERENT TYPES WHICH ARE AT VARIOUS STAGES OF TECHNICAL DEVELOPMENT. EACH HAS ITS OWN VOCAL PROPONENTS WHO GENERALLY DON'T LIKE THE OTHER TYPES. APPLICATION AREAS WILL VARY BY CELL TYPE. THE ONLY CERTAINTY IS THAT CURRENT CELLS ARE RARELY COST-EFFECTIVE EXCEPT IN ONE OR TWO USES WHERE COSTS DONT'T COUNT.

FUTURE COST REDUCTIONS ARE DISCUSSED BASED UPON NEW TECHNOLOGIES AND ECONOMIES OF SCALE. WILL THESE REDUCTIONS BE ENOUGH TO PERMIT THE ECONOMIC USE OF FUEL CELLS IN THIS CENTURY?

AS WE INVESTIGATED THE STATUS OF THE TECHNOLOGY, WE BECAME PAINFULLY AWARE THAT, AS SO OFTEN HAPPENS THESE DAYS, THE JAPANESE APPEAR TO HAVE A BIG LEAD. "ARE WE STILL IN THE BALL GAME?" BECAME AN OBVIOUS QUESTION.

AS WE LOOKED FURTHER, WE BECAME AWARE THAT A NUMBER OF CANADIAN SCIENTISTS AND SEVERAL COMPANIES WERE CERTAINLY STILL IN THE RACE.

AS FUEL CELLS ARE ENTERING THE THRESHOLD OF COMMERCIALIZATION, THE IDEA OF HAVING A WORKSHOP TO DISCUSS THE STATUS AND COMMERCIAL OUTLOOK IN ONTARIO AND CANADA BECAME ATTRACTIVE. WITH THE ACTIVE SUPPORT OF ENERGY MINES AND RESOURCES CANADA, WE HAVE INVITED YOU HERE TODAY TO DISCUSS THE WONDERFUL WORLD OF FUEL CELLS. WE REQUEST YOUR ADVICE AND INPUT ON THREE KEY QUESTION.

1. WHAT - IF ANYTHING - SHOULD THE CANADIAN AND ONTARIO GOVERNMENTS BE DOING TO SUPPORT THE DEVELOPMENT AND COMMERCIALIZATION OF FUEL CELLS?

2. WILL GOVERNMENT FUNDING SIGNIFICANTLY ADVANCE THIS COMMERCIALIZATION?

3. CAN CANADIAN COMPANIES PROFIT FROM FUEL CELLS?

WE ARE HAPPY TO SEE SUCH A LARGE ATTENDANCE TODAY. AT ONE TIME, WE WONDERED IF WE WOULD BE ABLE TO HOLD THE MEETING IN ONE OF OUR BOARD ROOMS. OBVIOUSLY, THERE IS AN INTEREST IN FUEL CELLS.

I'M SURE WE WILL ALL LEARN A LOT FROM TODAY'S SPEAKERS. HOWEVER, PLEASE REMEMBER THAT TODAY'S SESSION HAS BEEN CALLED A WORKSHOP. YOUR WORK FOR TODAY IS TO GIVE US YOUR INDIVIDUAL AND COLLECTIVE ANSWERS TO THE QUESTIONS I HAVE JUST ASKED. AT THE END OF THE DAY, WE HAVE ASKED DR. WARD TO SUMMARIZE YOUR INPUT.

THANK YOU.

FUEL CELL ACTIVITIES IN CANADA

Important contributions in the development of fuel cell technology, and its applications, have been carried out in Canada. Co-operative efforts between government agencies, private companies, electric utilities, and gas utilities, have produced some promising results as described in the following text.

Hydro Quebec was the first Canadian electrical utility to actively evaluate fuel cells, with the purchase and testing of six United Technologies, 12.5 kW units, in 1972, as part of the Gas Research Institute's Target program. Development work on electrolysis began in the early 1980s to determine the feasibility of hydrogen production by electrolysis as a means of electrical energy storage. In September 1984, Hydro Quebec purchased and installed one United Technologies (now International Fuel Cells) 40 kW Phosphoric Acid Fuel Cell (PAFC) unit at their Varennes facility, to test the concept of producing electricity from electrolytic hydrogen.

The fuel cell plant modified to run on pure hydrogen (no fuel reformer required), operated for over 8,000 hours, mostly at 10 kW. The electrical efficiency of the plant remained constant at 40.0 percent between 20 kW to 40 kW, and 36 percent efficiency at 10 kW.

The concept of using the hydrogen cycle for electrical energy storage, although uneconomic, was technically feasible. An integrated electrolysis, H_2 gas compression/storage and fuel cell power plant facility is now installed at Varennes.

Hydro Quebec is currently involved in a study for the Canadian Electrical Association, in conjunction with the Ecole Polytechnique du Montreal, to assess the fuel processing options available for the use of fuel cells in communities remote from the electrical grid. The study will investigate the various fuel reformers which have been developed to convert a hydrogen carrier fuel to H_2, to fuel the cell. Fuel costs, methods of transportation and storage, and ease of fuel handling restrict the types of fuel being considered. The fuel cell type considered for this study is the Phosphoric Acid Fuel Cell, the only commercially available fuel cell technology which can supply, at this time, multi-kilowatts to multi-megawatts of electricity at 'reasonable' cost (i.e., approaching the cost of electricity via conventional methods).

BC Hydro has investigated potential applications for fuel cells in electric utility systems since 1971. BC Hydro supported by Energy, Mines and Resources Canada (EMR) installed an International Fuel Cell (IFC) 40 kW PAFC power plant in a road mobile trailer and tested the operating characteristics of the system. In 1985, with funding support from Ontario Hydro, BC Hydro began testing the 40 kW PAFC power plant as a complementary project to the on-site fuel cell testing program carried out by the Gas Research Institute in the United States.

Successful operation and testing of the 40 kW PAFC power plant, in both 'grid-isolated' and 'grid-connect' modes, occurred between November 7, 1985, and May 1, 1987.

The fuel cell power plant (FCPP) located at the BC Hydro R&D Centre in Surrey, B.C. first operated in the grid-isolated mode, providing electricity for the lighting of the main floor of the R&D Centre and domestic hot water heating for the Centre, from November 7, 1985 to September 24, 1986. During October, 1986, the power plant was shut down to allow the installation of a grid connect unit. The FCPP then operated in a 'grid-connected' mode from November 3, 1986 to May 1, 1987. The site had a grid-independent load (main floor lighting) which was automatically connected in the event of the loss of the grid. The electric output of the grid-connected plant was controlled by the dispatched power set point at 37 kW and the fuel cell operation was unaffected by the electrical demand of the building. Fuel cell heat was again used for domestic hot water heating.

The power plant was maintained and operated in the grid-isolated mode of operation for a cumulative 5253.6 hours, and in a grid-connected mode of operation for a cumulative 2688.0 hours.

The average grid-isolated electrical generation efficiency, based on a Lower Heating Value of natural gas of 34,600 KJ/m^3n, was 28.9 percent with a "best 30 minutes" performance of 39.3 percent. The average grid-isolated thermal recovery efficiency was 15.0 percent with the "best 30 minutes" recovery being 39.0 percent.

The average grid-connected electrical generation efficiency was 39.4 percent with the "best 30 minutes" performance at 40.8 percent. The average grid-connected thermal recovery efficiency was 21.1 percent with a "best 30 minutes" recovery of 39.3 percent.

There were no failures of the unique components: the fuel cell stack or fuel processor. Failures were primarily with mechanical and electronic logic components in the auxiliary systems.

B.C. Hydro is now conducting an on-site demonstration of the same 40 kW PAFC power plant at an aquatic centre in Delta, B.C. B.C. Hydro, EMR Canada and Ontario Hydro are the principle supporters of this demonstration, with additional funding support coming from several gas utilities. The fuel cell was installed at the aquatic centre in the fall of 1987 and began operation on December 8, 1987. The fuel cell has run continuously for 1000 hours since then, supplying 37 kW of electricity to the centre and an equivalent amount of heat to warm the swimming pool at the centre. The demonstration is scheduled to proceed for a minimum 6 months, with the option of continuing a further six months should operation prove acceptable. This demonstration project will help address concerns regarding reliability and ease of use of fuel cell technology in a non-utility environment.

Significant advances in the development of solid polymer electrolyte (SPE) fuel cell technology have been made recently by a Canadian company, Ballard Technologies Corporation (BTC) of North Vancouver, British Columbia, with funding support from EMR Canada and the Department of National Defence. BTC's conventional SPE fuel cell design uses a Nafion membrane sandwiched between two platinum catalyzed porous carbon electrodes. The BTC fuel cell design also incorporates a selective oxidation process to convert harmful CO in the fuel gas and oxidant feed streams to CO_2, which can be safely rejected by the system. BTC has a design for a 10 kW module fuelled by H_2/O_2 for use in submarines, that would weigh 59 kg (130 lb) and occupy 0.04 m^3 (1.3 ft^3). The latest commercial product, primarily for military applications, is a 2 kW unit consisting of a pair of 54-cell stacks.

In 1986, BTC undertook to test a new polymer membrane produced by DOW Chemical. In a new SPE fuel cell using this Dow Experimental Membrane (DEM), current densities of approximately 4 A/cm^2 at 0.5 V cell voltage were attained. This is roughly a quadrupling of the current density, and hence power density, previously achieved using Nafion as the electrolyte membrane. Work continues on the development of this material, which promises better economics for SPE fuel cells in the future.

In 1987, the Ontario Ministry of Energy supported the development and testing of an integrated hydrogen storage system and fuel cell stack at the Thermodynamics and Kinetics Laboratory, at the University of Toronto, that would produce 30 W at 6 V for a period of eight hours. At the required power output of 30 W the five-cell stack had an operating efficiency of 49 percent. At the largest measured power output of 42 W with 3 volts, the efficiency of the stack had decreased to 40 percent.

When the fuel cell and hydrogen storage system are combined a mobile (DC) power supply is produced. This system could eventually replace batteries in certain applications.

In summary, Canadian companies and utilities, with the support of government, have been able to produce significant products, as well as useful results and data for the development and application of fuel cell technology.

Prepared By:

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APR 05 1999

CANADIAN BACKGROUND PAPER
FUEL CELL WORKSHOP

(N.R. Beck, W.A. Adams, D.D. McLeod)

1. Overview

1.1 General Overview

There was very little activity related to fuel cells in Canada, other than basic research at several Canadian universities, prior to the implementation of the National Energy Program in 1980. At that time, it was determined that the initial objective should be to acquire hands-on experience with existing technology before pursuing a research program in Canada. The major player was the National Research Council of Canada (NRCC) which managed the national program under the Panel on Energy Research and Development (PERD). The lead role for the national program has since passed from NRCC to Energy, Mines and Resources Canada (EMR), a department of the federal government.

Work is underway in four main areas:

1. Solid Polymer Electrolyte Fuel Cells (SPEFC)
2. Alkaline Fuel Cells (AFC)
3. Materials for Fuel Cells
4. Fuel Cell Applications

1.2 National Project

The Department of National Defence (DND) supports work at Ballard Technologies Corporation (BTC) related to Solid Polymer Electrolyte Fuel Cells. R&D related to the fuel cell polymer membrane is supported by EMR.

No. _____

Alkaline Fuel Cell work is undertaken at the Centre for Hydrogen and Electrochemical Studies at the University of Toronto (supported by EMR). At the Electrochemical Science and Technology Centre at the University of Ottawa work is directed at medical-related uses for both AFC and SPEFC systems.

The Canada Centre for Mineral and Energy Technology (CANMET) of EMR is engaged in R&D related to materials for electrochemical applications, primarily electrodes and electrolytes based on beta-alumina. Electrocatalysis research for improved electrodes is being performed by several university groups, Atomic Energy of Canada and Hydro-Québec.

EMR is currently supporting the demonstration of a 40 kW phosphoric acid fuel cell by a provincial utility, B.C. Hydro and Power Authority, in a commercial application. This demonstration began as part of the U.S. Gas Research Institute project and is supported by a number of other Canadian gas and electric utilities. Another Canadian utility, Hydro-Québec, operates a 40kW unit in its own project.

1.3 Private Sector R&D

In addition to the government and industry supported university-based R&D, the Canadian private sector conducts some R&D in-house in several companies. Ballard Technology Corp. is working on membrane technology for SPEFC applications. ALCAN International and Huron Chemicals have R&D efforts to develop improved air cathode technology.

2. R&D on Fuel Cells

2.1 Solid Polymer Electrolyte Fuel Cell

Ballard Technologies Corporation (BTC) has been developing SPEFC technology in conjunction with the Canadian Department of National Defence since late 1983. During that time, BTC has addressed the classical problems that have been asssociated with SPEFC technology and made substantial improvements. BTC has done this by using a focussed engineering approach. As a result, BTC has become a world leader in SPEFC technology.

Classical problem areas have included water management and gas distribution over electrode surfaces, operation on reformed fuels and, of course, cost.

Water management and gas distribution has been successfully engineered by BTC. This achievement is shown by successful operation of multi-cell kW-sized power sections using air for the oxidant.

Convenient fuels, like liquid methanol, can be processed to yield hydrogen rich "reformate". This reformate contains varying amounts of carbon monoxide (CO). At low temperatures ($\lesssim 100°C$), even small amounts of CO will "poison" the platinum catalyst used in the SPEFC. Therefore, operation of the low temperature SPEFC on reformed fuel gases containing carbon monoxide was at an impasse. The CO poisoned the platinum catalyst causing dramatic decays in performance. While others were developing "CO tolerant catalysts", BTC solved the problem by using an external process which selectively converts the CO in the reformed fuel gas to non-poisonous carbon dioxide, harmless to the cell.

Cost reduction has been addressed through the substitution of graphite cell plate hardware for high cost metal. However, the most dramatic cost reduction has been made by improving power output. A new membrane, developed by Dow Chemical, together with BTC's proprietary high performance membrane electrode assembly and fuel cell hardware, has allowed BTC to operate at four times the previous state-of-the-art for current and power density. BTC's demonstrated current and power densities of over 4A cm^{-2} (4000 A/ft^2) and over 2W cm^{-2} (2 kW/ft^2) have not yet been equalled.

In addition to technological advances, BTC has marketed and sold SPEFC products. Power sections have been sold to and are being operated by a US submersible company and the UK Ministry of Defence.

BTC is working with the Canadian Department of National Defence to develop, by 1990, a 4 kW methanol/air SPEFC Portable Field Generator for the Army. Activities include a 5 fold cell-size scale up and the engineering of independent power systems.

Table 1 shows continuous and maximum ratings of the MK V Power Section using either the current commercially available Nafion membrane from DuPont or the new experimental membrane from DOW, with H_2/O_2 or reformate/air as fuel and oxidant.

Table 1 - Net Power Output (Watts)

	H_2/O_2 (50/50) Psig	Reformate/Air (50/50) Psig
Dupont - Nafion Membrane		
Continuous	6,000	3,500
Maximum	7,500	5,000
DOW - Experimental Membrane		
Continuous	15,000	8,0000
Maximum	21,000	10,000

Portable power and electric transportation applications in sizes 4 to 20 kW for civilian defence applications will be supported in future projects and commercialization is expected by the mid-1990's.

2.2 Alkaline Fuel Cells

Canadian interest in alkaline fuel cell (AFC) technology is centred in the Department of Mechanical Engineering, University of Toronto and other related efforts in Ontario that began in

the late 1970's. At this time, studies of the status of fuel cell technology and analyses of options for the development of fuel cells in Canada were conducted for the Federal Departments of Transport and National Defence. The availability of low-cost electric energy in Canada would make it possible to electrolytically provide an inexpensive source of clean (CO_2 free) hydrogen at a cost close to that of synthetic natural gas. Furthermore, Canada has a strong electrochemical hydrogen production industry. The conclusion of these studies was that the development of alkaline fuel cell technology for mobile applications would be the best choice for a Canadian program. This is still a valid conclusion in 1988 based on a hydrogen energy currency concept. (However, recent progress in SPE fuel cell technology indicates that SPE fuel cells also show great promise). Work on AFC technology was conducted for a few years in the Institute for Hydrogen Systems near Toronto, but this program was ended about 1986. Parts of the program have continued in the Department of Mechanical Engineering at the University of Toronto where commercial opportunities to exploit several improvements in AFC technology are being pursued, especially for low power (<100W) specialty applications such as in the medical device (external power source for artificial heart program) or in defence areas. Research on the production of hydrogen for these highly portable applications and in the development of highly active low noble metal loaded catalysts has been a feature of this development effort. The system is operated at ambient pressure and slightly above room temperature. Other commercial activity to exploit related AFC technology in Canada is continuing at a low level in the Toronto area.

Development work on the engineering of a range of sizes of fuel cell modules from 30W up to larger sizes depending on applications will continue. System thermal and water management will be addressed as well as hydrogen supply in micro fuel cell applications for medical-related uses.

2.3 Materials

The Canada Centre for Mineral and Energy Technology (CANMET) began work in 1982 on the development of electrolytes based on beta-alumina for application in a solid electrolyte fuel cell. Methods for producing the hydronium form of the ceramic have been developed and patented (Canadian P.A.#4859464, 1985).

The potential utilization of these hydronium electrolytes has been demonstrated by the construction of a number of different types of electrochemical cells. Current work at CANMET is focused on the improvement of the electrolyte and electrode components. CANMET is collaborating with a number of researchers in W. Germany, Mexico, Israel, Denmark, Japan and Italy in evaluating these hydronium-based cells in various applications including fuel cells, sensors, electrolyzers and electrosynthesizers.

Electrocatalysis research related to basic kinetic and mechanistic studies of cathode and anode electrodes in fuel cells has been supported by federal government strategic and operating research grants in the Department of Chemistry at the University of Ottawa since the 1950's. Recent work has revealed details of the role of active platinum and palladium and the state of chemisorbed H in the operation of reversible H_2 electrodes especially in the case where the practical performance of electrodes, is to be studied at high current densities. Work on electrodes for battery and fuel cell application has been conducted by a number of Canadian companies including ALCAN International which maintains an electrochemical research program in Kingston, Ontario and Huron Chemicals also in Kingston. The Department of National Defence maintains a fuel cell test laboratory at the Royal Military College in Kingston, Ontario and is supporting research on electrochemical

materials in the Electrochemical Science & Technology Centre of the University of Ottawa. The Chalk River Nuclear Research Establishment of Atomic Energy of Canada maintains a catalyst research laboratory that has developed considerable technology relating to the electrocatalytic recombination of hydrogen. The Electrochemical Section of the Institut de Recherche d'Hydro Quebec (IREQ) has developed material research capability in the area of electrocatalysis of hydrogen.

2.4 Fuel Cell Applications

Canada has in place a program to evaluate and demonstrate the use of fuel cells. In 1984, a 40kW phosphoric acid fuel cell (PAFC) was purchased from United Technologies Corp. (UTC) by the National Research Council of Canada. The fuel cell was mounted in a mobile installation and was operated in both grid-independent and grid-connected modes in British Columbia by B.C. Hydro. Following these successful tests, the fuel cell has been moved to a swimming pool facility where it supplies heat for the pool and electricity for the pumps and lighting. The unit is fueled by natural gas and has operated for a cumulative total of over 10,000 hours. The longest continuous run with no shutdown of any type was 2,205 hours.

The project will provide real-life data from a commercial application which will allow decisions to be made by utilities regarding the use of fuel cells in their systems. Twelve Canadian electric and gas utilities are involved in this demonstration.

Hydro-Québec initiated a program in the 1970's to evaluate combined water electrolysis and fuel cell technologies for electrical energy storage. In 1972, Hydro-Québec tested six 12.5kW phosphoric acid units in the TARGET program. In 1984, a

40kW phosphoric acid UTC fuel cell was purchased. The fuel cell was modified to operate on pure H_2. The plant has operated for over 8000 hours and the energy efficiency has been 40.0% (energy content of H_2 to electrical energy).

Future work would address the use of fuel cells for power generation in remote communities to which the electrical grid does not extend. There is also consideration being given to operating and evaluating a new International Fuel Cell 200 kW phosphoric acid fuel cell.

3. Summary of Collaborative Areas of Interest

1. Research on non-noble metal catalysts to reduce the cost of AFC technology. Research to include basic studies of the kinetics and mechanisms of anodic and cathodic fuel cell electrode operation as an aid in the design of highly efficient (60%) electrodes.

2. Studies of the production of hydrogen from improved reformer design.

3. Investigation of factors related to the operational lifetime and economics of SPE and alkaline fuel cells by a system engineering approach based on careful selection of materials for all fuel cell components.

4. Novel applications for solid electrolytes in fuel cells, sensors, electrolyzers and electrosynthesizers.

5. Research on improved membranes and catalysts for SPEFC technology.

6. Sharing of results from fuel cell application demonstrations.

COMMERCIALIZATION OF LARGE SCALE FUEL CELLS

Mr. Ed Gillis
Electric Power Research Institute, Palo Alto, California

INTRODUCTION:

EPRI has sponsored fuel cell research and demonstration since its inception fifteen years ago. For the past two years, EPRI has actively attempted to stimulate the demonstration of Phosphoric Acid fuel cells (PAFC) by electric utilities in the United States as a means to assist in their commercial introduction in utility service. We have not succeeded in stimulating sufficient interest by individual utility companies in the U.S. to fund the demonstration of even a single 11 MW unit at this time. I will attempt to describe in this paper why commercialization of this technology--a technology our utility company advisors continue to say is important to them--has not proceeded.

ROLE OF FUEL CELLS IN U.S. UTILITY SERVICE:

During the past two years we have worked closely with a number of utility companies to better define the applications for fuel cells on utility systems, how utilities would use them, their value to utilities and the market that might exist for them. All of this was performed as part of the activity to stimulate interest in demonstrating 11 MW PAFC plants, so the conclusions apply only to plants having characteristics similar to near-term PAFC as shown in Table 1, and to the utility business climate in the U.S. which unfortunately was undergoing major changes at the time. The bottom line of these studies was that the PAFC is a niche technology that primarily benefits urban and municipal utilities where in-city siting of power plants is difficult due to environmental factors. The studies indicated that the PAFC could capture about 10-20% of the intermediate and peaking generation in the U.S. This is about the same market potential as all energy storage technologies combined so it is significant. Combustion turbines and combined-cycle plants were predicted to capture the bulk of this market.

The studies assumed an installed cost of the initial market entry PAFC plants of $1300/kW (in January 1986 U.S. dollars) decreasing to $800/kW in mature production in the post 2000 time frame. The market was, of course, very sensitive to PAFC capital cost: a ten percent higher installed cost reduces the estimated market by 80% while 10% lower cost increases it by nearly 300%. Clearly achieving the capital cost targets is essential for successful commercialization.

The initial high value market consisted of a mix of environmentally constrained-, co-generation- and small utility- applications. Municipal utilities in particular, many of which have peak loads only in the 100 MW range, are attracted to the fuel cell because there aren't many attractive alternatives in the 1 to 10 MW size power plants they desire. Some of the investor owned utilities (which tend to be much larger systems than the municipals) actually viewed the 10 MW size as a liability and would only consider larger fuel cells and then only when they would be clearly more economical than alternatives such as combined cycle plants.

Table 1

First Generation PAFC Characteristics*

Rating, MW	11
Heat rate, Btu/kWh HHV	
100%	8300
50%	9200
Emissions, lb/10^6 Btu, N.G.	
NO_x	0.006
SO_x	0.0004
Particulate	0.002
Noise, dB(A)	60 at 100 ft. from boundary
Electrical Power	11 MW net AC 11 MVAR leading or lagging 1.1 P.U. max. fault current, 1 cycle 1 MW/second ramp rate

*Extracted from IFC PC23 Product Description

Several large utilities had limited applications for PAFC to help solve transmission problems: in one instance the PAFC could replace some "must run" generation and still maintain system reliability at a lower capacity factor because of its fast response capability. Another utility believed they might be able to site a fuel cell (but nothing else) in a particular location that would allow cancelling construction of an underground transmission line. The value of the PAFC in these instances was above $1000/kW.

Presumably we can conclude from these studies that commercialization of something with the characteristics of the PAFC can proceed naturally when acceptable operability and reliability have been demonstrated and when it can be purchased for $1300/kW. The key question then is how to get to that point.

MARKET ENTRY PROPOSITIONS:

Several years ago, International Fuel Cells offered to produce a limited number of prototype 11 MW fuel cell power plants for electric utility evaluation and use. This offer was unusual in that it was a completely private-sector proposition; it did not request nor anticipate any Federal government funding. To limit the technical risk to the prospective utility buyers, the offer was for turn-key plants at a fixed price and guaranteed performance. The offer had an inverted price structure with early units being more expensive. The average price for the 250 MW limited production quantity was approximately $2000/kW.

This proposition received virtually no U.S. utility interest or support, probably due to a number of factors:

- The inverted price structure, i.e., no one wanted to be first.
- Most utilities did not need additional capacity for at least 10 years.
- The unit cost exceeded their value hence a portion of their cost would not be allowed in the rate base.

EPRI attempted to get the program moving by trying to develop a few utility consortia to share the costs of constructing a few demonstration units. This too has not succeeded; few utilities wanted to serve as the host for such a project, and not enough other utilities willing to contribute to the demonstrations could be found to reach the necessary funding level.

We believe that there are a number of factors that have contributed to the utility's disinterest:

- The regulatory review process in the U.S. is heavily biased towards penalizing utility risk takers, and these propositions placed all the technical and financial risk on the utilities and manufacturers.
- The utility industry in the U.S. is undergoing a fundamental change. De facto deregulation is underway, and utilities are being encouraged to purchase power rather than generators. Much of the new generation being contracted for now or planned for the near future will not be utility

owned. The special features of a fuel cell have little value to a non-regulated bulk-power producer.

The absence of Federal support for the market entry and demonstration propositions contributed to the utility industries lack of interest. Recent history shows that it is unlikely that any new utility-scale technology can be commercialized in the U.S. without Federal government involvement. Examples of this include the renewable energy resources such as solar- and wind-power; their deployment has stalled recently since special tax benefits have been canceled. The Clean Coal Technology program, where the Government can cost-share up to 50%, is another example where some stimulus is shown to be needed to implement even near-term moderate-risk technologies. The U.S. utility industry is simply unwilling to undertake any unessential technical or financial risk at this time.

COMMERCIALIZATION PROSPECTS:

It should be clear from the above remarks that it will be difficult to use the electric utility industry to commercialize (at least) the PAFC. The large scale of this type of project means that costs will be in the tens of millions of dollars and the industry will not put that much money at risk. The industry also wants evidence that the new technology will be clearly superior to the existing technology in either performance or preferably cost; incremental improvements will be discounted. In this respect, commercialization of the advanced fuel cells may be easier if their efficiency or economics are clearly superior. However technical risk will still need to be controlled closely.

SMALL SCALE FUEL CELLS

S. Abens
Energy Research Corporation

Small fuel cell power sources continue to be of interest for a wide range of potential applications in both the aerospace, military and the civilian sector.

The role of fuel cell in the various space missions, including the Space Shuttle, has been widely publicized. A major potential role for small fuel cells in other than aerospace uses is in applications now employing diesel engine gensets. When compared to conventional diesel generators, fuel cells offer the following advantages:

1. Very low noise. Fuel cells are, for all practical purposes, inaudible.
2. Lack of vibration. Power generation is non-mechanical.
3. Low emissions. In general, there are no objectionable emissions from fuel cells.
4. Better fuel efficiency, especially at part load.
5. Much better oxygen efficiency.

Against these advantages weigh two major fuel cell disadvantages:

1. Warmup time - 15 minutes with phosphoric acid fuel cell, less with alkaline or solid polymer electrolyte systems. Molten carbonate and solid oxide systems would probably take longer to warm up.
2. Cost. A methanol fired phosphoric acid fuel cell would cost in the $500-1,000/kW range even in a mature market.

Of the various chemistries, the alkaline fuel cell (AFC), solid polymer electrolyte (SPE), and phosphoric acid fuel cell (PAFC) have received the most development effort. However, the molten carbonate fuel cell (MCFC) system may become an excellent alternative, especially in higher power rating systems where fuel efficiency is a primary concern.

While the megawatt-size fuel cell development has been driven mainly by energy and economic considerations, small fuel cell designs are governed more by mission requirements. Without the alkaline fuel cell system which was developed at great cost in the early sixties, the Appollo mission could not have been accomplished. Similarly, the present Space Shuttle program depends on the use of the alkaline hydrogen-oxygen fuel cell.

An earlier space program, the Gemini terrestrial orbit mission in the mid-sixties made use of solid polymer electrolyte (SPE) fuel cells. This mission was probably the earliest practical application of fuel cell power plants.

While the space applications represent the ultimate remote power requirements where fuel cells may have no substitute, a number of terrestrial applications exist where small fuel cells may be a desirable alternative to more conventional power sources. Many of these fall in the power range of between 1 and about 50 kilowatts, although, on-site integrated energy systems (OS/IES) are now planned at the 200 kW power level. The characteristics typically sought for these power sources are competitive or acceptable life cycle costs combined with superior performance as compared with alternate power source choices.

In the early seventies, the U.S. Army initiated a program for the development of small fuel cell power plants for field use. These power sources were based on the use of reformed methanol in phosphoric acid fuel cells (PAFC) and several advanced development models with power output rated between 1.5 and 5 kilowatts were built and demonstrated by Energy Research Corporation and by International Fuel Cells, Inc. Energy Research Corporation also delivered a 5 kW unit with water recovery to the U.S. Air Force.

Efforts are also continuing to capitalize on the investment and experience gained with the alkaline and SPE systems by adapting them to terrestrial operating requirements. The major challenge with these systems for most applications is to achieve operation with hydrocarbon fuels and air rather than with pristine hydrogen and oxygen which are practical for use in space but uneconomical elsewhere.

The U.S. Army chose methanol for small fuel cell power source development after earlier work with a gasoline cracker did not produce a viable fuel system for field use. Likewise, later work at ERC showed that reforming of diesel fuel is difficult for generation of hydrogen for a small portable fuel cell power source. Methanol continues to be viewed as by far the most attractive fuel for small fuel cells.

Alternate approaches to storage and generation of hydrogen such as metal hydrides are nevertheless pursued, especially by European fuel cell developers. This effort is driven by the desire to utilize alkaline or SPE fuel cells, which are poisoned by the CO_2 and CO byproducts of hydrocarbon reforming. The complex fuel systems and means for product water management required for these fuel cells

tend to negate the high power density of the electrochemical portion of the fuel cell power source.

At the present time, several fuel cell power sources are under development with public funding in the U.S., Europe, and Japan. The U.S. Department of Energy is supporting development of phosphoric acid fuel cell power plants for city buses. Two contracts are in place, one with Energy Research Corporation and one with Booze Allen, with the fuel cell supplied by Engelhard/Fuji. Power level for this application will be about 100 kilowatts, and methanol will be used as the fuel. Also with phosphoric acid fuel cells, IFC is developing a 200 kW O/IES power plant with GRI funding. This plant is designed to use natural gas. In Europe, alkaline fuel cells are under development by ELENCO and Siemens.

In Japan, Fuji Electric is a notable small fuel cell developer, having operated PAFC power units on both methanol and natural gas. A 5 kW methanol lift truck development is underway as a joint project with Engelhard Industries.

FUEL CELL TECHNOLOGY

FOR THE

GAS INDUSTRY

Randy J. Petri
Institute of Gas Technology

Presented at

FUEL CELLS
POTENTIAL OPPORTUNITIES
IN CANADA

Toronto, Ontario, Canada
28 April 1988

ELECTRIC POWER GENERATION (1986)

	QUADS
COAL	14.5
NUCLEAR	4.5
NATURAL GAS	2.7
PETROLEUM	1.5
INDUSTRIAL/COMMERCIAL COGENERATION	1.0

IGT

FUEL CELL MARKET

TECHNOLOGY	RESIDENTIAL	COMMERCIAL	INDUSTRIAL	UTILITY
PHOSPHORIC ACID	10 KW*	40 KW*	200 KW**	4.5 – 11 MW*
MOLTEN CARBONATE		◄---- 100 KW – 10 MW ----►		
SOLID OXIDE	◄---- 5 KW – 500 KW ----►			

* COMPLETE PLANT DEMONSTRATION

** STACK DEMONSTRATION

IGT

GRI 40 KW FIELD TEST

- 46 UNITS AT 42 SITES
- 37 ENTITIES INVOLVED
- DEC. '83 TO JAN. '87: 310,000 HOURS OF OPERATION
- 17 POWER PLANTS REACHED 8000 HOURS OF OPERATION
- 1 UNIT EXCEEDED 12000 HOURS
- AVERAGE AVAILABILITY 63% (TARGET: 55 TO 65%)
- PROBLEMS: CONTROLS, PUMPS AND VALVES, COOLING SYSTEM
- FUEL CELL COMPONENTS: RELATIVELY TROUBLE-FREE (REFORMER, STACK, INVERTER)

IGT

GRI PAFC GOALS

- 200 KW EARLY-ENTRY SYSTEM
- ELECTRICAL EFFICIENCY 36% (HHV) OVER 30 -100% RATED OUTPUT
- OVERALL EFFICIENCY (ELEC + THERMAL) 80% (HHV)
- ELECTRICAL FORM: 3 ϕ, 60 HZ, 120/208V
- FUEL INPUT -- NATURAL GAS, 4-14 INCHES WATER COLUMN
- UNATTENDED, LOAD FOLLOWING OPERATION
- NOISE LEVEL: 60 dbA MAXIMUM AT 15 FEET
- EMISSIONS (LBS/MMBTU INPUT):

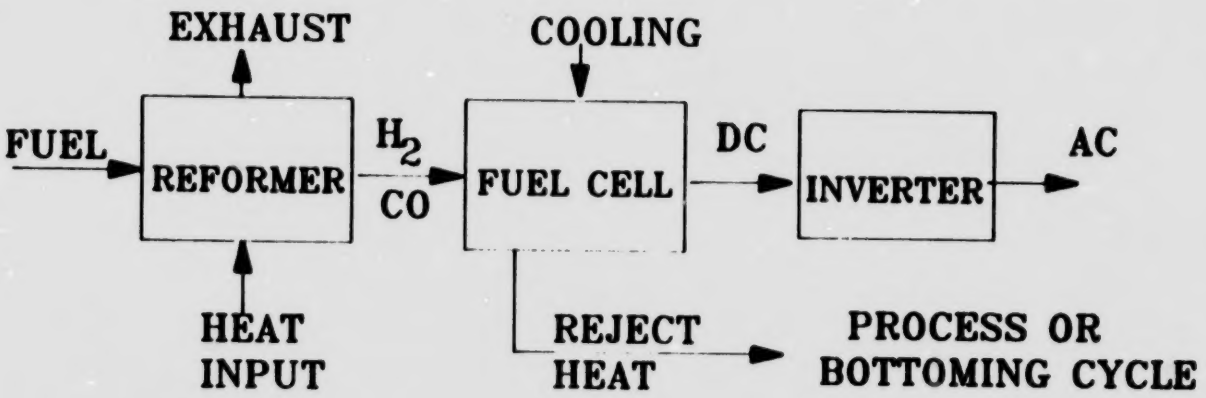
NO_X -	0.02;
SO_2	0.00003
PARTICULATE	0.000003
SMOKE	0
HYDROCARONS	0.02

- $1000 -- 1500/INSTALLED KILOWATT IN HIGH PRODUCTION

IGT

FUEL PROCESSING

INDIRECT:



DIRECT:

$$CH_4 + H_2O \longrightarrow CO + 3H_2$$

$$H_2 + CO_3^{=} \ (O^{=}) \longrightarrow H_2O + CO_2$$

- Eliminate Reformer
- Increase Efficiency
- Reduce Cooling Load

IGT

SOLID OXIDE DESIGNS

ELECTROLYTE: DOPED $ZR0_2$ (Ca, Y)

OPERATION: 1000 C (1800 F)

GRI CONTRACTS

TUBULAR: WESTINGHOUSE

PLANAR: CERAMATEC WITH INTERNATIONAL FUEL CELL CORP.

MONOLITHIC: ARGONNE NATIONAL LAB WITH COMBUSTION ENGINEERING
GARRETT/AIRESEARCH

IGT

MOLTEN CARBONATE FUEL CELL REACTIONS

OPERATION: 650°C (1200°F)

ANODE:

$$H_2 + CO_3^{=} \longrightarrow H_2O + CO_2 + 2e^-$$

$$CO + H_2O \longrightarrow H_2 + CO$$

$$(CH_4 + H_2O \longrightarrow CO + 3H_2)$$

CATHODE:

$$1/2\ O_2 + CO_2 + 2e^- \longrightarrow CO_3^{=}$$

NET:

$$H_2(CO) + 1/2\ O_2 \longrightarrow H_2O(CO_2)$$

IGT

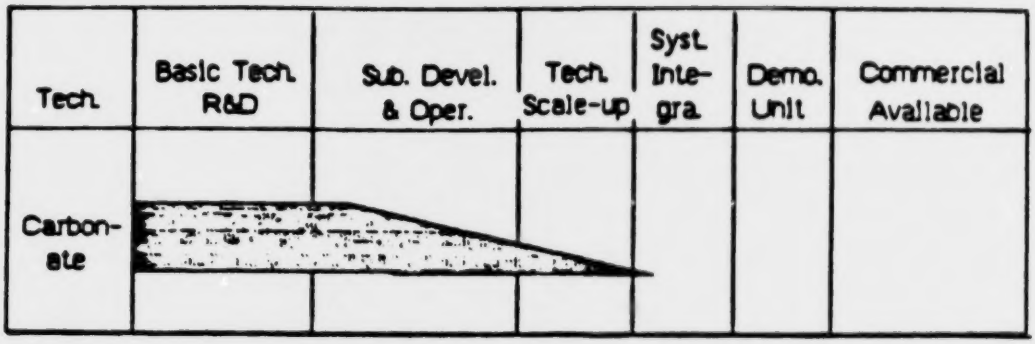
CARBONATE FUEL CELL
PLANT EFFICIENCY

FUEL	BOTTOMING CYCLE	EFFICIENCY
COAL*	NO	37%
NATURAL GAS	NO	45%
COAL*	YES	47%
NATURAL GAS	YES	60%
NATURAL GAS (Internal Reforming)	NO	60+%

* COAL CONVERSION EFFICIENCY = 78%.

IGT

CARBONATE TECHNOLOGY STATUS



● Resolved ◒ Unverified ○ Unresolved

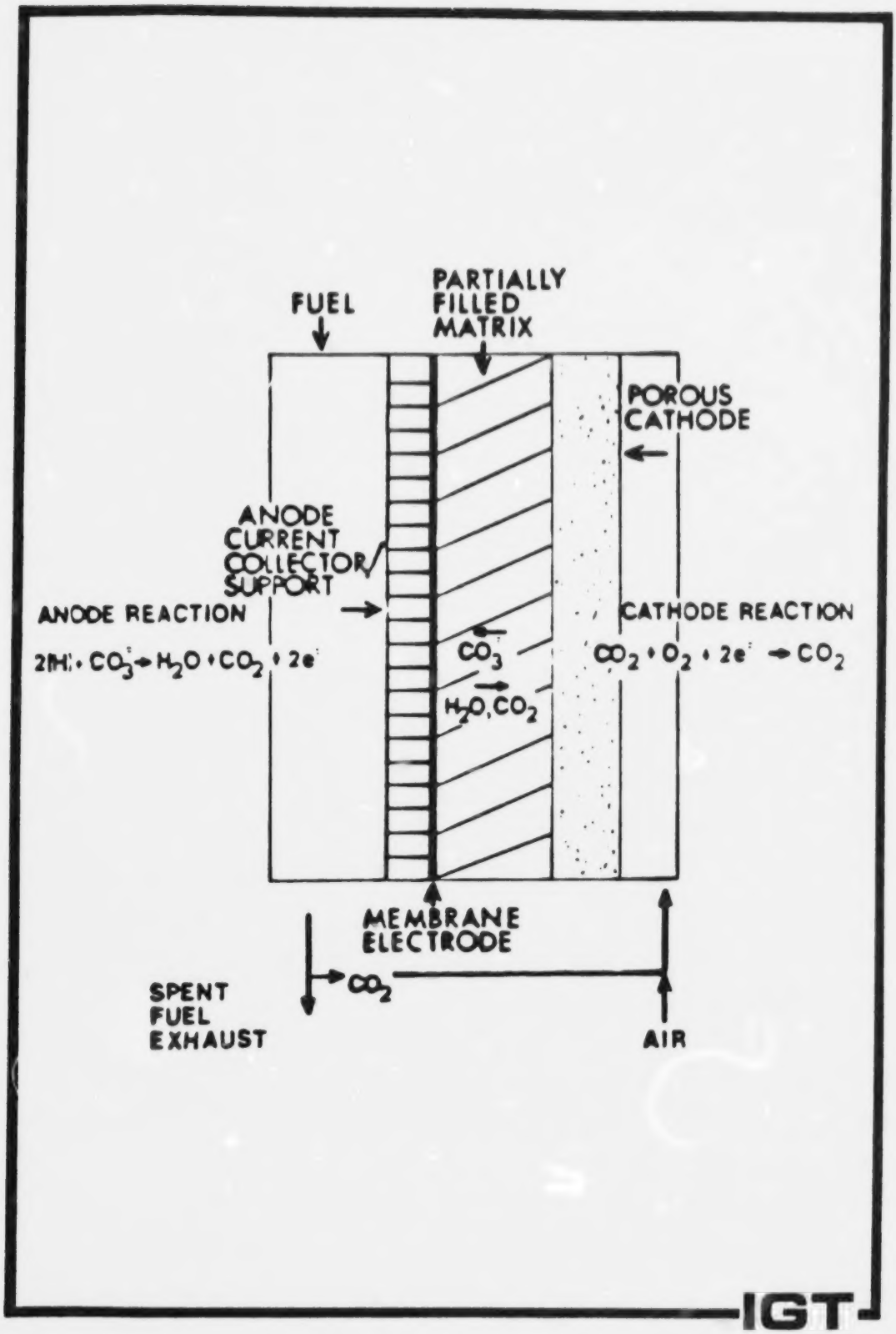
	1987 Status
Thermal Cycling	●
Anode Creep	●
Recrystallization of Electrolyte Barrier	●
Matrix (Tile) Cracking	●
Cell Voltage Consistency	●
Electrolyte Loss	◒
Corrosion of Cathode Current Collector	◒
Cathode Solubility	◒
Cathode Strength	◒
Reforming Catalyst Contamination	◒
System Development	◒
Heat Recovery	○
Sulfur Tolerance	◒
Cost	◒

58/9

MCFC DEVELOPMENTAL AREAS (IGT)

- ANODE
  - -- SULFUR TOLERANCE
  - -- IMPROVED STRENGTH
- CATHODE DISSOLUTION
- CORROSION
- INTERNAL REFORMING CATALYST
- TAPE CASTING OF ELECTRODES AND ELECTROLYTE
- CONTAMINANT RESISTANT CELL DESIGN
- INTERNALLY MANIFOLDED STACK DESIGN

IGT


FUEL
PARTIALLY FILLED MATRIX
POROUS CATHODE
ANODE CURRENT COLLECTOR/ SUPPORT
ANODE REACTION
$2H_2 + CO_3^= \rightarrow H_2O + CO_2 + 2e^-$
$CO_3^=$
H_2O, CO_2
CATHODE REACTION
$CO_2 + O_2 + 2e^- \rightarrow CO_2^=$
MEMBRANE ELECTRODE
CO_2
SPENT FUEL EXHAUST
AIR
IGT

FEATURES OF BARRIER ANODE CELL

- H_2S -- COS ISOLATED FROM ELECTROLYTE
- REFORMING CATALYST DESIGNS POSSIBLE
- DIRECT CO_2 TRANSFER TO CATHODE
- CO_2 RECYCLE (AND CLEANUP) LESSENED
- ELECTROLYTE LOSS BY EVAPORATION GREATLY IMPEDED
- CORROSION AT ANODE REDUCED

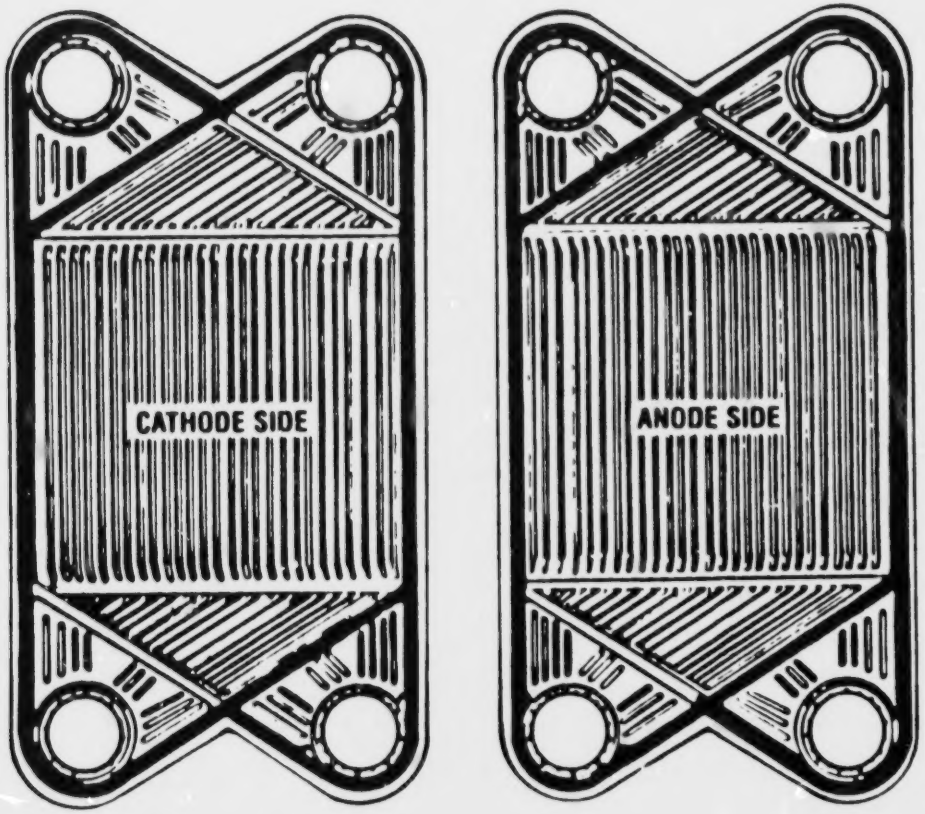
IGT

IMHEX™ MCFC STACK CONCEPT

- INTERNAL MANIFOLDING
- PENETRATED MATRIX
- ANALOGOUS TO PLATE-TYPE HEAT EXCHANGER
- SINGLE-PIECE SEPARATOR PLATE/CURRENT COLLECTOR
- COMPLIANT WET SEALS
- TAPE CAST, FLAT CELL COMPONENTS
- SCALABLE TECHNOLOGY

IGT

SCHEMATIC REPRESENTATION OF IMHEX™ PLATES

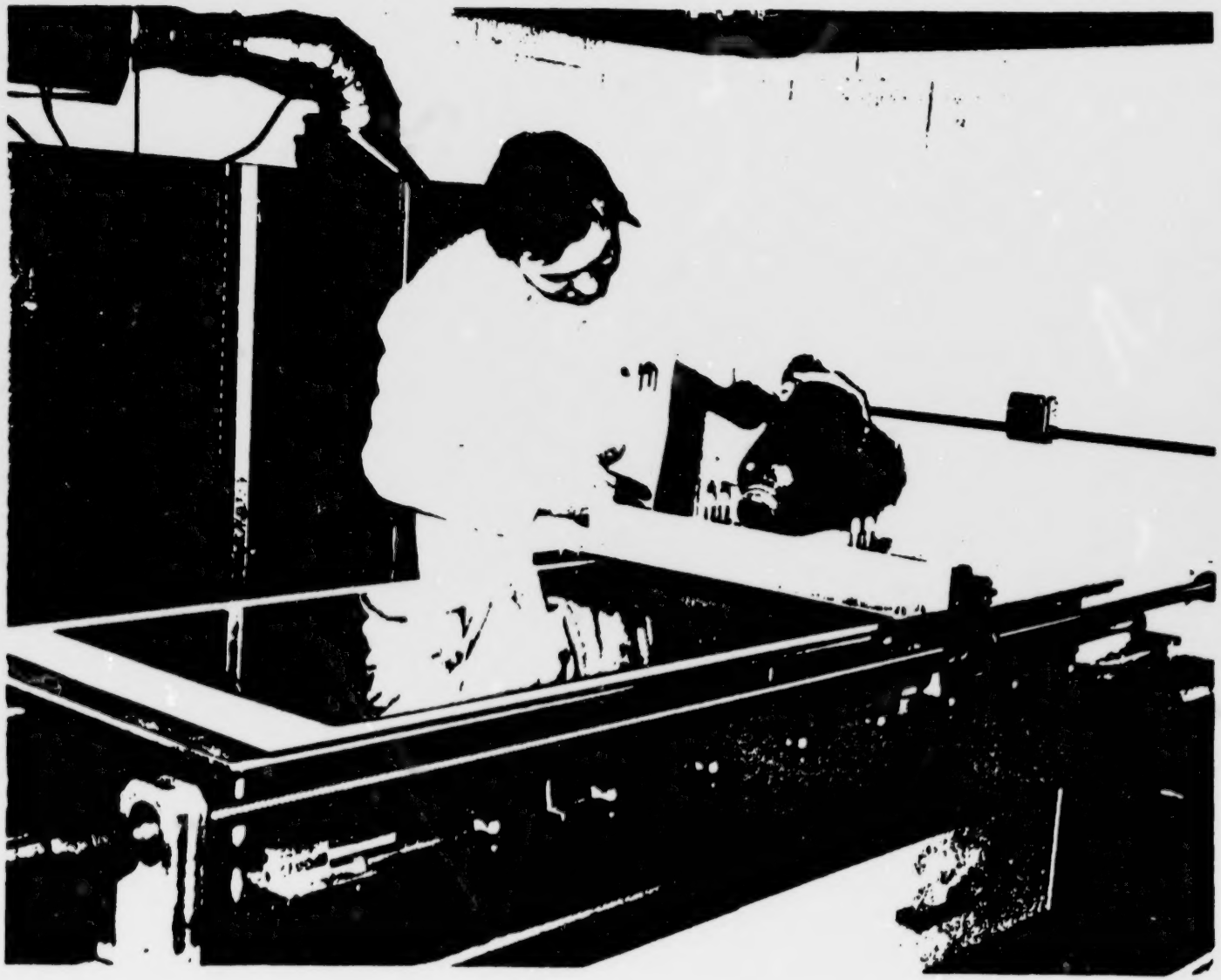


IGT

IMHEX™ DESIGN/DEVELOPMENT APPROACH

- DESIGN CONFIGURATION ANALYSIS
- PRESSURE DROP MODELING
- COLD-FLOW TESTING
  - — VERIFY PRESSURE DROPS
  - — EVALUATE FLOW UNIFORMITY
- STRESS MODELING TO SPECIFY SHEET THICKNESS
- FORMING AND JOINING TRIALS
- STACK TESTING

IGT



IGT STACK TESTING FACILITY 1

- 2 kW, 1 ft^2
- ATMOSPHERIC PRESSURE
- FEED GASES
  - FUEL: H_2, CO_2 (CO OBTAINED BY SHIFTING)
  - OXIDANT: CO_2, O_2, N_2
- COMPUTER CONTROL AND MONITORING

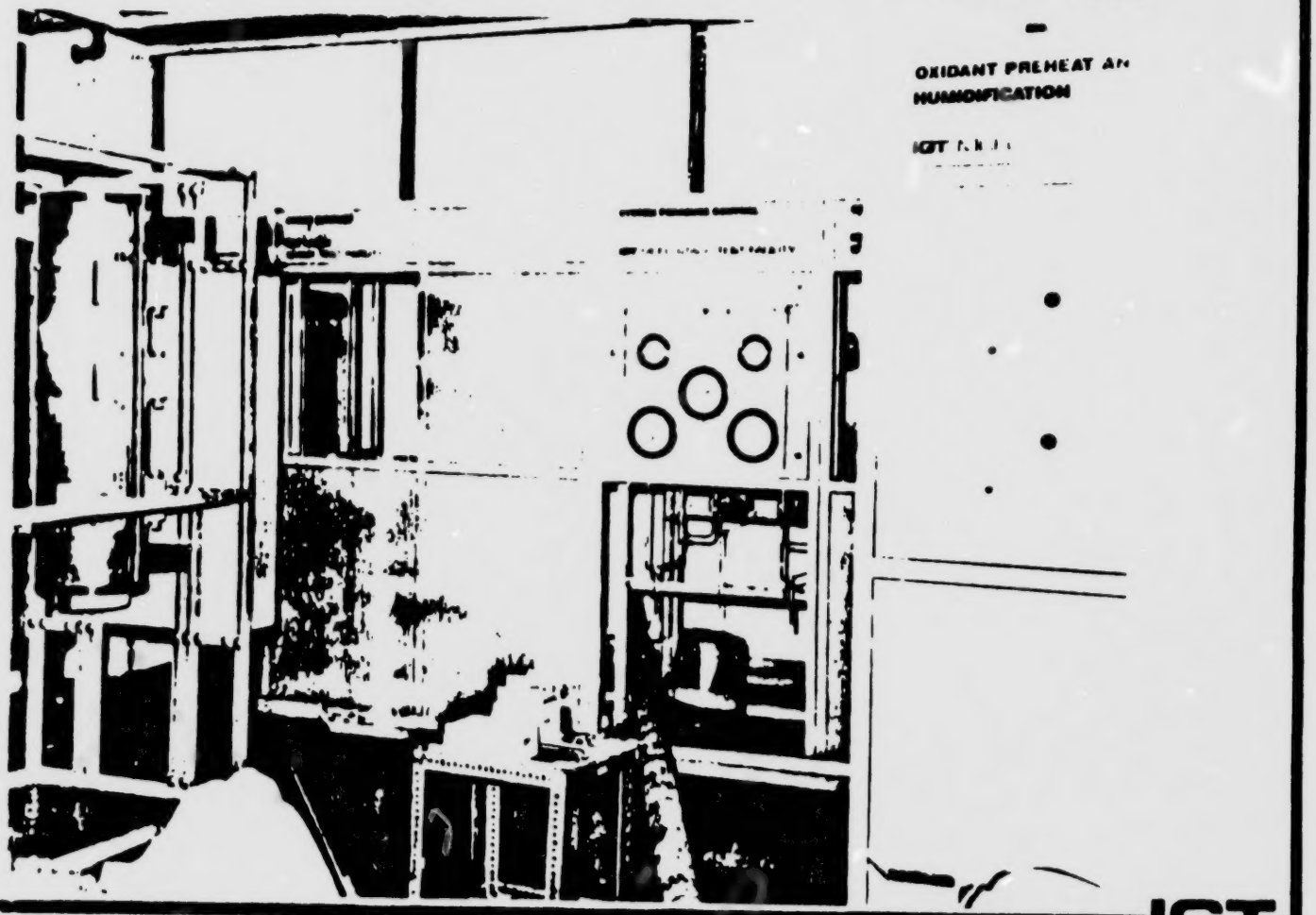
IGT

IGT STACK TESTING FACILITY 2

- 2-3 kW, 1 ft^2
- UP TO 10 ATMOSPHERES
- FEED GASES
  - — FUEL: H_2, CO_2, CH_4, N_2
    (CO OBTAINED BY SHIFTING)
  - — OXIDANT: CO_2, AIR, N_2, O_2
- COMPUTER CONTROL, SAFETY, DATA ACQUISITION AND REDUCTION

IGT

FACILITY 2: UNDER CONSTRUCTION — DECEMBER 1986



SUMMARY

- IMHEX™ STACK CONCEPT OFFERS SIGNIFICANT ADVANTAGES OVER EXTERNAL MANIFOLDING AND NON-PENETRATED INTERNAL MANIFOLDING DESIGNS
- IGT'S DESIGN ANALYSIS PROGRESSING TO CULMINATE IN PROOF-OFCONCEPT IN 1988 STACK TESTS

IGT

FUTURE PLANNING AT IGT

- TRANSITION MCFC TO COMMERCIAL ENDEAVOR
- FORMATION OF M-C POWER INC.
- CONTINUE RESEARCH ON OTHER FUEL CELL CONCEPTS
- DEVELOP ELECTROCHEMICAL REACTORS FOR CH_4 USING FUEL CELL EXPERTISE AND EXPERIENCE

IGT

WORKSHOP: FUEL CELLS - POTENTIAL OPPORTUNITIES IN CANADA

Fuel Cells: An Electrical Utility Viewpoint

Mr. Blair R. Seckington - Ontario Hydro

INTRODUCTION

I'd like to thank at this time the Ontario Ministry of Energy and Energy Mines and Resources for sponsoring this forum. There is a lot of activity in the various energy related circles which each of us here represent. It is good to be able to step back in a gathering such as this to see what fuel cell activity is ongoing and where fuel cells might fit in the future and how to optimize their development.

My name is Blair Seckington, just as the schedule says. That may not mean an awful lot to many of you, so let me tell you a little of my background.

Within the vastness of Ontario Hydro that most of the public in Ontario hears about, there are a number of small but vigorous groups. Their goal collectively is to keep Ontario's lights on and motors running at a cost-effective price, now and to keep it that way.

One of these groups has among its responsibilities the monitoring, evaluation and in some cases participation in the development of renewable and advanced fossil and novel energy concepts/technologies. It operates within a given budget, trying to optimize its program's flexibility and to maximize the performance of its limited resources.

That particular group is called the Alternate Energy Unit in our Design and Construction Branch. It currently consists of only six persons. Fuel Cells fall within its mandate as an advanced "novel" energy process.

I am that group's Supervising Design Engineer. As such I am responsible for development of a plan or direction, for providing recommendations/comments to more senior staff on our/other's involvement, and for subsequent implementation in several areas including fuel cells.

I should point out that ours is not the only group with responsibilities in any given technology area. Our Research Division does excellent R&D in a number of areas including electrochemistry, and as a result to some measure in advancing generic fuel cell materials/manufacturing development. Similarly, other departments in Ontario Hydro may focus on specific aspects of technology. We tend to view advanced and/or novel technology on an applied, but more conceptual basis.

OBJECTIVE

Now that you know who I am, I'd like to be able to tell you that fuel cells are the answer to our future energy technology needs. They aren't of course. They are only one potential option whose niche has not yet been clearly defined.

In view of this, I developed my talk:

(1) to summarize our own efforts to date;

(2) to highlight from an electric utility perspective the major incentives behind and roadblocks to further fuel cell development; and lastly

(3) to dream a little about what might be.

Since others will discuss other uses, my talk will focus largely on utility applications. It may only touch on others which may in fact be nearer term and be stepping stones in its development for use by electric utilities.

ONTARIO HYDRO'S POSITION AND PROGRAM

Our Position

To put it bluntly, Ontario Hydro is interested in any feasible energy technology which will help it to fulfill its mandated responsibilities. If a process, a fuel, a technology can be utilized reliably, safely, and in a manner at least economically and environmentally competitive with existing proven approaches, we're certainly ready to listen and where it's appropriate follow it up with more than just words. This is certainly demonstrated by comments made recently by our President on conservation and non-utility generation (Toronto Globe and Mail - April 9, 1988).

Fuel cells applications have been addressed by Ontario Hydro several times over the last fifteen years. The latest economic evaluation was in 1985 as a part of our Demand Supply Options study.

In general terms, fuel cells are for Ontario Hydro and most electric utilities, a technology having an uncertain potential as both a future generation source and a customer side or demand option, requiring further significant development and testing to improve performance, reliability and cost. They are not now cost effective utility electricity generators. As such utilities, particularly those whose rates are regulated by Public Utility Commissions, are reluctant to invest in their early development/demonstration.

We believe that on a commercial basis, fuel cells will not make a significant impact as an electricity source for utilities until well after the year 2000. There could however be a significant niche market to provide ultimate market development funding. Ultimately, their large scale application for most non-utility markets may be tied to the development of a more hydrogen oriented society.

Our Program

Ontario Hydro's program in fuel cells has been somewhat typical of utilities. We maintain a watching brief on new developments and periodically evaluate commercial fuel cell economics and/or demonstration programs.

The initial high investment and development cost of prototype units has been a deterrent to involvement in large demonstrations, while the future is unclear. In the United States, some utilities are concerned about recovering their development costs with a return or with setting new generation cost standards. Some Public Utility Commissions may not allow all of such an R&D program. PURPA, on the other hand, has raised the latter possibility. Most programs have focused on government purchased or subsidized units, with testing undertaken and only partially co-funded by the electric utilities, usually as part of a consortium of utility backers. This was certainly the case for most recent EPRI projects in the US and for the 40 kW PAFC unit initially purchased by the National Research council and operated by BC Hydro, with some co-funding by Ontario Hydro (approximately $165,000) and others over a period of two years.

Dr. Mike Papic of BC Hydro will be making a presentation later in the program on the 40 kW PAFC unit (slide 1) work. As our part in their overall program has been very small, I will leave its description to him. I would like to say, however, that we've been very pleased with BC Hydro's program and believe it continues to be a very worthwhile effort.

Late last year, our group submitted a draft proposal to the Ontario Ministry of Energy to initiate discussions on a smaller fuel cell demonstration project. It focused on a 5 to 10 kw solid polymer fuel cell operating at an Ontario chlor-alkali facility using surplus hydrogen currently being flared. The Provincial Ministry of Energy had expressed some interest in funding such a project with some participation from other participants. We had suggested our role could be as project facilitator/manager. Subsequently, Ministry staff have decided to investigate the concept further themselves.

Our Research Division have also been very actively seeking support of their electrochemistry fuel cell materials/manufacturing work on solid oxide systems. This program is in the initial stages and is being conducted by Dr. Ramesh Kalia in co-operation with members of the University of Toronto.

So Where Do Fuel Cells Fit for Electric Utilities

Right now, fuel cells for electric utilities generally don't fit in. Their economics do not justify their up-front, risk accentuated, capital cost. Everyone knows this. It's no surprise. It's also the case for PV and Wind energy technologies, but that doesn't mean giving up on them altogether. It means looking for the realistic potential for the technology, deciding on the means and costs of getting to that position, and optimizing the resulting development program/funding/participation.

It may be that large fuel cell development for utilities may have to piggyback smaller niche market applications, just as it has for PV. Smaller specialized vehicle systems or advanced space systems or remote community applications could provide the initial development cash flow needed. Perhaps it is a series of programs similar in nature to the one we suggested earlier to the Ministry. This may appear to slow down the potential pace of development, but, on the other hand, it may be workable. The flexibility to go this approach should be viewed as a definite plus for the technology.

In the future, the potential for electric utility fuel cell implementation will be highly utility/site specific. This lack of an easily forecast market is certainly a negative. However, in some cases smaller cogeneration units for commercial and industrial owners may make sense for demand management or parallel supply for utility. In others, larger utility standalone systems may be an economic option. In others still, fuel cells could serve as part of an off-peak nuclear/hydro energy storage and peak generation scheme. And again in others as part of a remote grid power system. The avenues for development remain open and this additional flexibility is a plus.

Fuel flexibility is for electric utilities a major concern. Today we see natural gas surpluses, and favourable natural gas contract prices. These certainly favour those fuel cell technologies which can use natural gas, preferably directly. The downside of course is that there is some concern over the future availability and price of natural gas in light of the upturn in demand, particularly in the U.S. Also no hard evidence exists that the fuel cell technology will have any significant cost advantages over other advanced natural gas technologies. There is of course from a fuel flexibility perspective, the case for a clean coal gasifier - fuel cell combination but this will take considerable further development.

The environmental implications of the fuel cell offers considerable development incentive. The electrochemical reaction produces electricity at very high efficiencies with very low pollutant emissions, relative even to other natural gas technologies. It could even be conceptually sited in small blocks of power modules throughout the load centre. On the downside the lower energy density of such a facility may require more space, on an acre/MW basis, than other comparable natural gas technologies.

The development of fuel cell customer side generation to minimize future large supply side facilities and as heat sources may also be beneficial in some cases. This would be particularly true in the time period when/if hydrogen is a significant energy currency. If fuel cell parallel generation becomes very significant however, the development of operating procedures will be required to ensure no significant adverse effects impact the operation or maintenance of the Bulk Electricity System, particularly as a result of the multiple or large DC to AC interfaces.

One could continue thinking and listing positives and negatives, but perhaps the most critical steps/roadblocks to electric utility applications are as follows:

- R&D must result in designs which can be semi-commercially and mass produced at a low initial capital cost, be reliable and relatively maintenance-free and have a reasonably long life.

- Users must, allowing for developments in other current and advanced electricity technologies, determine appropriate targets for a matrix of capital cost, reliability, operating costs and life projections.

- Prototype demonstrations must adequately demonstrate significant progress under "real" conditions towards the reliabilities, operating costs, and life targets set by users and delineate how they will ultimately be achieved, when, and under what circumstances.

The Bottom Line for Electric Utilities

The bottom line of my assessment for electric utilities, especially in Canada, is that they will not depend on a technology until it has been fully demonstrated to be cost effective and reliable. Secondly, very few public electric utilities in view of the high capital and development costs and uncertain future viability, will undertake to develop/commercialize a fuel cell design, on its own or as even a major part of any program. Despite this position most utilities would like to see the option remain available and develop to its potential.

The Dream

After that bottom line statement, I (will) now let my personal thoughts go. You know those kinds of dreams where you're waken feeling like you've had to make a major decision. That's how I see the future of fuel cell development, or many of the other new technologies for that matter.

My dream focuses on Canada, in the next few years, at the decision point. What are we going to do? Three major paths (each with numerous branches) are facing all of us and each of us? Do we choose path No. 1 where we ignore this (and other) technology and buy it from someone later if it works out and we want it? Do we choose path No. 2 where we seek to copy but improve on other's work, i.e. the PAFC? Or do we in taking stock of ourselves, evaluating our strengths, try to find a fully independent fuel cell R&D course?

Any of these paths could lead to a future for fuel cells in Canada, or not. All have costs and benefits. Each takes time and effort to get rolling. I don't know which is best in view of all of the demands on limited Canadian R&D dollars and personnel. I do know that we must proceed soon with our decision, and we'd better not take it haphazardly. We may not get a good second shot at it, and we will have mis-used a great deal of time and money.

It seems that I'm in good company with my dream. More and more it seems that our major political leaders are getting involved in the debate over new technology policy/development, and also in environmental matters. That's encouraging because they are significant national issues. From my perspective they both also impact electricity generation.

Recently the Federal Government held a major technology seminar here. Its focus was on a Canadian Program. Similarly the Premier Council's on the Economy, headed by Premier Peterson himself, sees a need to develop high technology industry in Ontario in order to compete in the future as a leading technologically competent nation in the overall world marketplace. Among the recommendations of the Council:

- Ontario should establish a risk-sharing fund to encourage export companies to invest in developing new products.

- Special tax incentives for new investment in R&D should reward the few Ontario based companies that do invest in R&D and assist in the growth of others ...

I can see beyond the year 2000 coal/fossil/renewable based energy centres. I can see among other things distributed and customer side installed fuel cells. I can see a booming high technology solid state/electrochemistry base in Ontario, with industry, university and government working together.

On the other hand, ...

R&D PRIORITIES

Enough of reterick, I would suggest to our Federal and Provincial Energy hosts that they maximize the benefit of this day and the interchange we're having. It should be followed and expanded up on by:

- developing on a continuous or periodic basis a Canadian consensus on the appropriate course of action for a future fuel cell program, including program priorities, and rational funding requirements/sources. It should do this being cognizant of other technology programs and possible synergisms;

- being open to supporting ongoing and new R&D work on fuel cell technology and applications, particularly by Canadian companies, especially where there are niche or spin-off benefits which maximize the return on the effort, but simultaneously advance the state of the technology;

- considering joint R&D and demonstration programs with the U.S. or Japan where Canadian companies would significantly benefit from and participate in the most advanced developments;

- ensuring that technical transfer mechanisms exist to keep potential user's well informed of ongoing work, its highlights and its problems.

I hope that these thoughts will provide some further discussion. I certainly look forward to hearing from the rest of the speakers and then from you in the Work Session.

FUEL CELLS FROM THE VIEWPOINT OF INDUSTRIAL USERS

Frank W. Spillers
Fuel Cell Association
Washington, D.C.

The industrial use of fuel cells will happen when the users feel comfortable with the projected economics and operating history. One must remember that the vast majority of potential industrial users know little, if anything, about fuel cells. Their day-to-day interest is in making pounds of product and fuel cell developers are just another vendor trying to sell another product they claim will help the industrial plant manager's operation. As with any other product, the plant manager wants to know the capital cost, his savings if he uses the product, and where the product has been shown to be effective (wants a proven product). With this modus operandi, how do you think the typical industrial plant manager will react to a pitch to buy fuel cells?--(1) Today's capital cost is extraordinarily high and we really cannot give assurance of future costs, (2) Cannot give assurance of plant savings, (3) There is no large industrial use history to give assurance of proven technology.

I know this description of the typical industrial plant manager may sound negative, especially from one involved in the fuel cell industry, but it is the real world and, after all, it is the real-world customer we are asking to put up his hard-earned money.

In tabular form I will list the impediments that fuel cell developers must deal with:

1. Capital Cost
2. Heat Rate
3. Cost/KWH
4. Operating History

We need to encourage the documentation of good, "hard" numbers on capital costs. One of the best starts toward this end is a report entitled "Cost Assessment of Fuel Cell Power Plants for Electric Utility Application" dated August 1987 and prepared by International Fuel Cells for the Electric Power Research Institute. This report is so good and so understandable that I have distributed it to several plant managers in my company. I also hope our association (Fuel Cell Association) can get permission to print a summary in our newsletter. In this report, market entry values of $1300 to $1500 installed costs for a phos acid system are given. At a fuel cell manufacturing rate of 1500 MW/yr., an installed cost of $1075/KW was projected and, at larger production volumes, the cost went down to $740/KW. Also, the advanced phos acid system was projected at $600/KW for the late 1990's. Believe me, capital costs like this will make many of our "hard-nose," "bottom-line" industrial plant managers take notice!

In addition to the previously stated good news on capital costs, this same report stated heat rates of 9300 BTU/KWH (HHV) for their 4.5 MW "Reference Plant" (Phosphoric Acid), 8300 BTU/KWH for their PC23 market-entry plant, and 7000 BTU/KWH for their late 1990's advanced phos acid system. Again, numbers like these will be of extreme interest to the typical industrial plant manager!

Next on the list of items of interest to the typical plant manager is the bottom-line cost/KWH. This final figure will only come about through actual operating history of demonstration units, although a rough calculation could be made using the previously quoted capital costs and heat rates. We really need the operating history and this, I believe, is the big impediment to the commercialization of fuel cells. Demonstration plants are needed in order to build this operating history. Demonstration plants are expensive but someway must be found to get them in operation--and soon! Many advanced technologies are lost at this same stage of development due to the large cost of this last barrier. I believe the technical people in our fuel cell community have made many innovative contributions and it is now time for the business and financial people to show us how innovative they can be.

The future potential for an industrial fuel cell market is tremendous in light of the previously discussed capital cost and heat rates. The most economical market entry point should be in those industries where by-product hydrogen is available. Also, an added plus would be at sites where the DC power output can be used without conversion to AC. Availability of by-product hydrogen eliminates the expense of hydrocarbon fuel reforming, although some purification of he hydrogen may be needed. The direct use of DC power eliminates the DC/AC invertor, although some DC regulations would probably be needed in most applications.

An industry meeting this criteria of by-product hydrogen and use of DC power is the chlor-alkali industry. Chlorine cells produce by-product hydrogen at the rate of approximately 1 pound per 34 pounds of chlorine and, being an electrolytic process, they use DC power. They consume approximately 1 KWH-DC/lb chlorine.

The following table shows the chlorine production capacity of the U.S. and Canadian chlor-alkali industry, the amount of by-product hydrogen produced, and the corresponding maximum capacity of fuel cells using the by-product hydrogen:

Cl_2 Capacity - U.S. = 11M tons/year
Canadian = 1.5 M tons/year

H_2 Capacity - U.S. = 650 M lb/year
Canadian = 89 M lb/year

U.S. Fuel Cell Potential = 500 to 700 MW
Canadian = 70 to 95 MW

Each chlor-alkali producing site would need to be studied individually to determine the value of fuel cells. For instance, a site that presently uses their by-product hydrogen for its chemical value would have less incentive than one that fuels a boiler.

Another factor in the chlor-alkali industry that will favor fuel cells is the trend toward less steam requirements for caustic evaporation as membrane cells replace diaphragm cells. Membrane cells produce a higher strength caustic which decreases evaporation steam needs. It so happens that fuel cells produce less steam than conventional power systems, thereby making them more valuable at industrial sites, such as chlor-alkali, where the steam demand is decreasing.

Ethylene production is a huge producer of by-product hydrogen where hydrogen is produced at about 0.07 lb/lb ethylene. The following table shows U.S. and Canadian capacity.

Ethylene Capacity - U.S. = 35 B lb/year
Canadian = 4 B lb/year

39 B lb. ethylene = 2.7 B lb/year of H_2 = approx. 2,200 MW

In most ethylene plants the hydrogen is valued at fuel value since it can be burned in the ethylene furnaces. There would be little need for DC power, therefore conversion to AC would be required.

Styrene is another producer of by-product hydrogen (approx. 0.019 lb. H_2/lb styrene):

Styrene Capacity - U.S. = 8.6 B lb/year
Canadian = 1.4 B lb/year

10 B lb Styrene = 190 M lb/year of H_2 = approx. 150 MW

Other industries that have by-product hydrogen include oil refining, sodium chlorate, etc.

In addition to industrial process applications for fuel cells, there are other industrial uses such as fork lift trucks and emergency power systems.

The world production of fork lifts is about 350,000 units per year. The most common units are 1 to 2.5 ton with average power ratings of about 4 KW. The trend is towards electric power (i.e., battery) with about 1/3 of the presently produced units being electric. There is probably a very near-term opportunity for fuel cells to replace batteries in the high-end (value) markets which are applications requiring three-shift operations. Three-shift operations are a problem due to the logistics of recharging, spare batteries, etc. As with most other fuel cell applications, the big need is to get demonstrations underway as soon as possible.

Many industrial sites have emergency power systems for use during power outages or temporary upsets in utility power supply. These units are usually IC engine generator sets which are sometimes even combined with storage batteries for more immediate load response. Heat rate is of little economic concern for emergency systems because of their limited operating time. Capital cost requirements are very competitive, with typical IC engine generator sets ranging from about $200/KW for large units to $600 for small units. Fuel cells will probably not compete, for a period of time, until capital costs come down, unless other benefits can be proven such as rapid load response, lower maintenance, etc. Again, it will take demonstrations to quantify these other potential benefits.

In closing, let me say that future industrial applications for fuel cells will depend on power production economics and to be competitive, fuel cells will have to compete with other power technologies such as gas turbine combined cycles where you have an installed cost of about $600 to $700/KW and a heat rate of about 8500 BTU/KWH. In addition, and very importantly, these competitive power systems have years of successful operating history behind them. It is imperative that the fuel cell industry develop good industrial demonstration projects if we are to compete in the real world marketplace. To be successful in the industrial market, fuel cell developers, must, as a minimum, keep their effort directed towards reducing cost per KW, reducing heat rate, and implementing demonstrations.

3/29/88
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FUEL CELLS FOR VEHICULAR APPLICATIONS

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ABSTRACT

The principal reason for the interest of the automotive industry in fuel cells (FC) is their potential to replace the internal combustion engine (ICE) by a power plant potentially capable of: improving fuel economy, and decreasing environmental damage.

Unlike ICE's the thermal efficiency of FC's increases under part load operation (predominantly characteristic for passenger car urban driving cycle). This gain in the efficiency of chemical-to-mechanical energy conversion can be as high as 100 %. Truck engines operate much of the time at (or near) full power, at which the gain in the fuel consumption efficiency by using FC's instead of diesel engine is considerably diminished, (except for alkaline cells, whose thermal efficiency is superior even at maximum power).

Fuel cells' emissions may be virtually free of CO, NO_x, unburned hydrocarbons, aldehydes and particulate matter. Absence of moving parts results in almost silent operation.

Present impediments for vehicular applications are connected with 1) immature technology and 2) high initial cost.

1) Development of FC technology was, and continues to be oriented towards space and stationary power plant requirements. Technical impediments for automotive applications vary with the FC type, each having a different set of problems. The long time scale required for the development effort and emergence of commercial opportunities stifles the incentive for the necessary R&D and demonstration activity. Consequently the progress to date has been slow and cannot be expected to accelerate within the near future. Improvements which might alleviate the present technical impediments include:

decrease of weight to power ratio: the actual vehicle fuel economy is a function not only of the average efficiency of the power plant but also of the vehicle weight. Presently,

FC's developed beyond single cells stage weigh at least twice as much as the IC engine. R&D possibilities: monolithic solid oxide FC (development at incipient stage)?; lightweight, fast-transient methanol reformer for solid polymer (SP)FC (prototype under tests at LANL)? effective CO_2 removal from fuel in alkaline (A)FC?; direct electrooxidation of methanol?

decrease of cold start time: presently the delay is of the order of 10 - 20 min at ambient temperature. R&D possibilities: hybridization with a light-weight battery?; with a small pressurized H_2/O_2 FC?; auxiliary heating from external power source?

fuel availability and management:

Pure hydrogen which would enable the use of AFC's might be the fuel of the future (hydrogen economy); at present its cost/BTU is estimated as 20% higher than that for coal-derived methanol. Storage in a) hydrides is - as yet - weight and volume inefficient; b) high pressure tanks would present safety problems in confined spaces and require severe energy expenditure (some 25% of hydrogen heating value for compression from 1 to 135 atm.).

Methanol's price is competitive with gasoline and its average thermal efficiency (in ICE) is about 10% higher. The conversion of infrastructure seems relatively easy. The best solution would be the direct cold combustion in FC's -- at present impractical owing to the poisoning of noble catalyst and its high loads. Systems using reformed methanol would have to prove lower cost and better over-all fuel economy than methanol-fueled ICE's.

Availability of platinum (required for acid fuel-cells seemingly closest to practical realization at about 40 g Pt/car) is disputed. Considering only the USA, introduction of 10% FC powered cars/year would remove in ten years (average life-time for a car) 400 tons Pt from world reserves estimated at 15600 tons. Thereafter, recycling would drop the "excess" demand to <1 ton/year. This simplistic scenario would affect little the world reserves estimated at 15600 tons. However, neither the effect on price, nor the political availability of Pt (imported almost exclusively from South Africa and USSR) can be forecast.

R&D possibilities: suitable catalysts for direct electrooxidation of methanol?; light-weight, fast-transient response reformers combined with a viable method of CO_2 removal from reformed fuel, enabling the use of AFC's?; replacement of Pt and/or further decrease of Pt load in acid FC's?.

Other fuels (including diesel) may be used in high temperature Solid Oxide (SO) FC's. The developers of the

Monolithic SOFC project extremely attractive characteristics (internal reforming, low cost, high effciency and high specific power). The incipient stage of development prohibits the evaluation of difficulties connected with the ceramic integrity, manufacturing of the intricate structure, heat management, etc.

2) In view of high component costs, immature technology and manufacturing problems the initial cost of the FC stack will be for a long time much higher than the cost of ICE's. The object of easiest market penetration is the city bus. For the purpose of fleet operation the reduced operational cost may compensate for the prohibitive price.

The passenger car market will be very difficult to penetrate, since, (apart from technical considerations affecting user's convenience) the consumer selects a vehicle on the basis of initial rather, than total life costs.

Therefore it seems that the market for FC powered automobiles will appear only under conditions enforced by 1) environmental dangers threatening national health, plant and animal life, or real estate (greenhouse effect); 2) drastic decrease in the availability and increase of price of conventional and alternative fuels.

These conditions will sooner or later materialize. Technically mature FC power plants should then be available. Since the problems impeding achievement of this stage are numerous, difficult and require a long time to solve, the R&D effort in the area of automotive FC's should continue at suitable levels.

Overcoming Impediments to Fuel Cell Commercialization

by Keith B. Prater and Paul F. Howard, Ballard Technologies Corporation, North Vancouver, B.C.

For over 100 years the fuel cell has been put forth as a simple, highly efficient device for the direct conversion of chemical energy into electric power. Significant progress has been made in fuel cell technology in recent years, and yet, with the single exception of manned space flight, fuel cells have failed to capture a spot in the market place. In this paper, we will present our views as to the major impediments to fuel cell commercialization and suggest approaches for overcoming them.

The four major impediments to fuel cell commercialization are:

1) High Capital Cost

2) Lack of Infrastructure

3) Risk Aversion of Potential Customers

4) Difficulties of Financing Fuel Cell Companies

While the relative importance of the four impediments discussed below may vary from one fuel cell technology to another or from one fuel cell company to another, we believe that each is, in some measure, generally pertinent. And, though most of the examples presented in this paper come from our own experiences with Solid Polymer Fuel Cell (SPFC) technology, we believe that they are representative, to a greater or lesser extent, of the situation for fuel cells as a whole.

1) HIGH CAPITAL COST

Fuel cells, at the moment, are often much more expensive, than a coal-fired steam turbine, a diesel generator, or a gasoline IC engine. In order to successfully commercialize fuel cells, one must either:

a) Reduce the capital cost of fuel cell technology to the point that it competes with existing technology, or

b) Identify existing markets in which the specific advantages of fuel cells will justify a price premium over competing technologies, or

c) Identify new applications which are not feasible in the absence of a fuel cell, but become possible as a result of the unique properties of fuel cell power sources.

At Ballard Technologies, we are following all three of these approaches.

a) Cost Reductions

Capital cost reductions can be accomplished by reducing the material and labour component while maintaining performance at a constant level and/or by improving performance while holding costs constant.

Materials Cost Reduction

SPFC technology has been branded as "too expensive" because of the cost of the platinum catalyst and the polymer electrolyte. This is a misleading conclusion. The costs of these materials represent a relatively insignificant portion of the overall cost of producing SPFC fuel cells for today's limited markets. In fact, the SPFC is intrinsically no more expensive than the Internal Combustion Engine (ICE) it will one day replace.

The ICE would be very costly if market demand were a few hundred units per year instead of million of units per year. Before the development of mass markets and mass production techniques, few would have believed that the modern car engine, with its hundreds of mechanical and electronic components, could be produced for a few hundred dollars. Yet in hindsight, that cost is taken for granted.

We expect that, with sufficient development effort and market requirements, the polymer electrolyte used in the SPFC will become just a "piece of plastic". To date, very little effort has gone into developing a cost effective polymer electrolyte for SPFCs--the materials that have been used have been developed for other applications with different market requirements.

The platinum catalyst also offers substantial opportunities for cost reduction. The platinum loading can already be substantially reduced from that used by GE in the space program. Test run at Ballard Technologies have shown that operation at platinum levels as low as 1 mg/cm^2 is possible. It is even possible that non-noble metal catalysts will be developed for use in low temperature fuel cells. Even accepting that some level of platinum catalyst may be required, it is almost totally recyclable.

In summary, substantial reductions in the materials and labour costs of SPFC and other fuel cells have been made. Further significant reductions can reasonable be expected to be made in the near future with further technical development and, more importantly, with the development of substantial markets.

Performance Improvement

The performance of a Ballard fuel cell using Nafion and a new DOW membrane as the polymer electrolyte is shown in Figure 1. One year ago, the Nafion would have represented state-of-the-art performance. Note that the voltage begins to drop significantly when the current density exceeds 900 A/ft^2 (ASF) (equivalent to

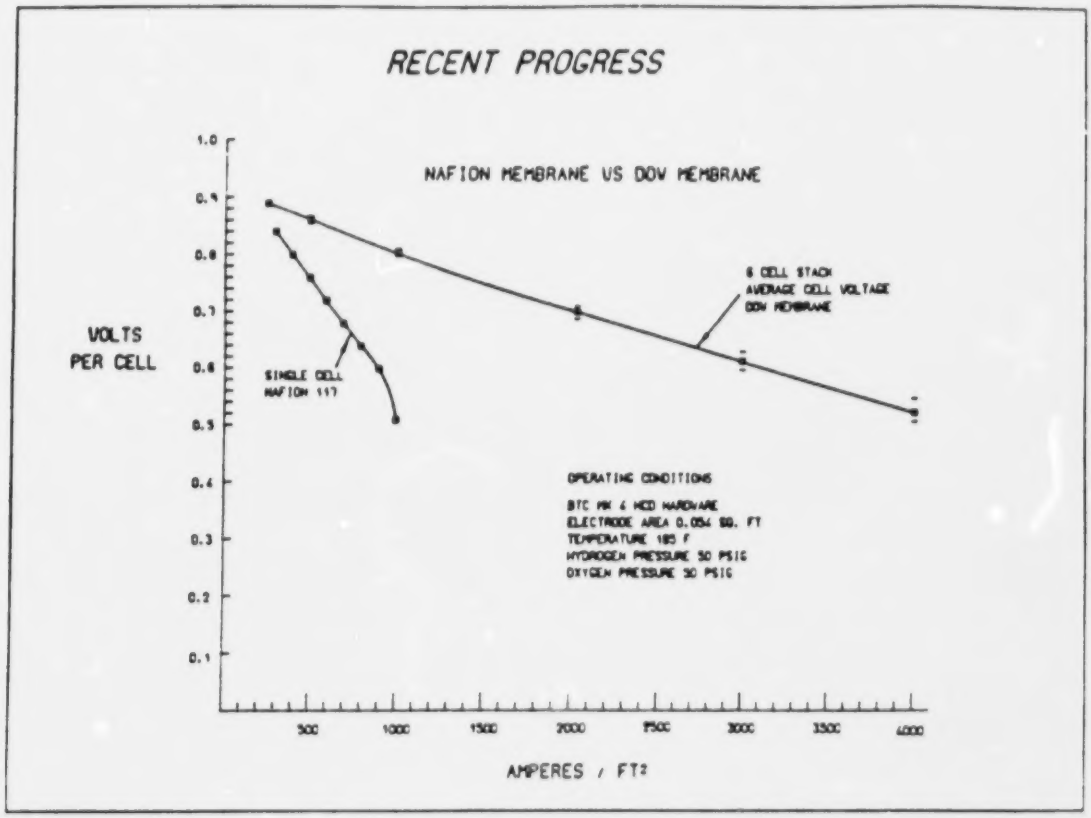
RECENT PROGRESS
NAFION MEMBRANE VS DOV MEMBRANE
VOLTS PER CELL
6 CELL STACK AVERAGE CELL VOLTAGE DOV MEMBRANE
SINGLE CELL NAFION 117
OPERATING CONDITIONS
BTC PH 4 HCO HARDWARE
ELECTRODE AREA 0.054 SQ. FT
TEMPERATURE 185 F
HYDROGEN PRESSURE 50 PSIG
OXYGEN PRESSURE 50 PSIG
AMPERES / FT²

Figure 1 - Voltage vs Current Density

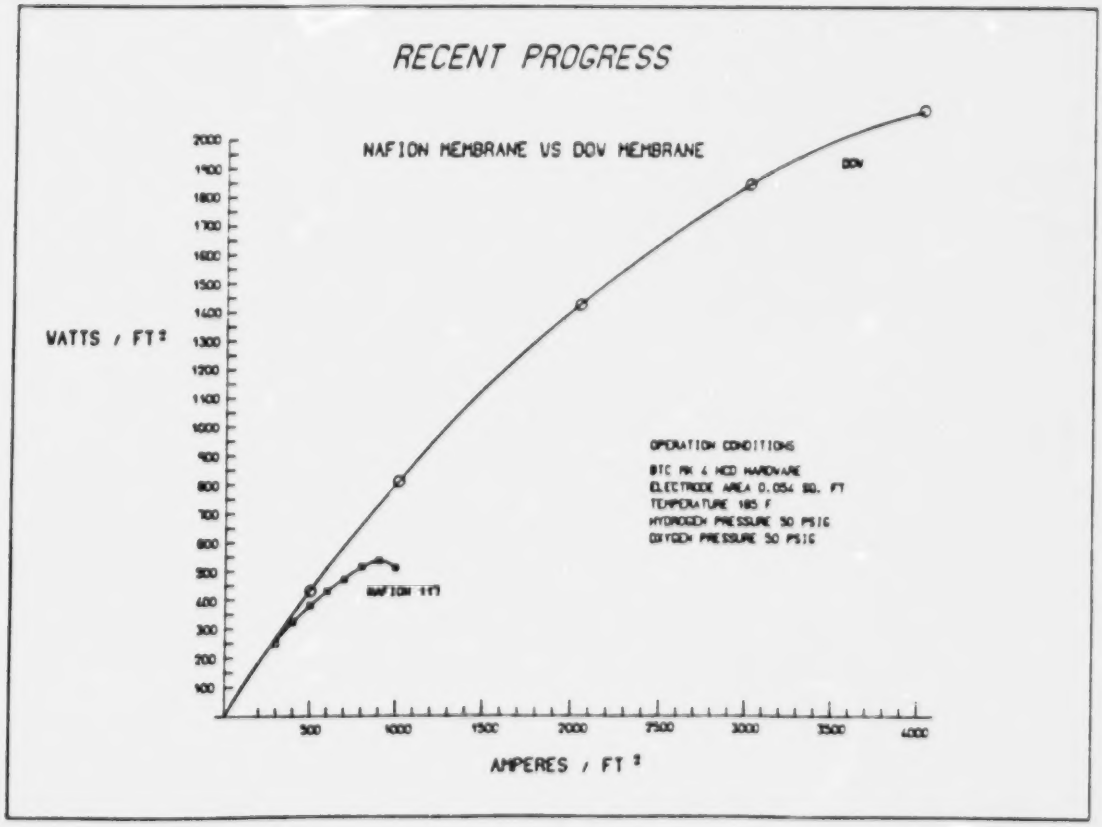

Figure 2 - Power Density vs Current Density

0.97 A/cm^2). The performance of the new Dow membrane in the same fuel cell hardware and at the same platinum loading as was used to obtain the data for the Nafion is also shown. Note that the voltage does not drop abruptly even at 4000 ASF (4.3 A/cm^2). Figure 2 presents a comparison of the two membranes showing power density. The power curve for Nafion peaks at about 500 W/ft^2 (WSF) (equivalent to 0.54 W/cm^2) at 900 ASF while the power density for the DOW has not peaked even at 4000 ASF. Ballard Technologies has demonstrated power densities in excess of 2000 WSF (2.2 W/cm^2) for extended periods.

The substitution of the Dow material, which is anticipated to cost about the same as Nafion, results in a four-fold increase in peak power with no increase in fuel cell capital cost. The cost per peak watt has thus been reduced by a factor of four by this performance improvement.

In summary, for any fuel cell system, performance improvement reduces the quantities of <u>all</u> material and labour required to generate a given amount of power and is therefore a more desirable approach. For this obvious reason then, efforts should be directed towards improving performance of fuel cell systems.

b) Markets Relying on Specific Fuel Cell Advantages

Even with the cost reductions identified above, and others being accomplished in other technologies, fuel cells are still usually more costly than existing, mass produced power sources. There are, however, markets in which cost is not the only important factor.

For a variety of military and scientific applications, the high temperatures generated by heat engines and the noise of internal combustion and turbine engines are severe disadvantages to the intended mission. Ballard Technologies is under contract to the Canadian DND to develop an SPFC replacement for diesel and gasoline-powered field generators. It is expected that the SPFC generators will provide reduced operating and life cycle costs while dramatically reducing the IR and noise signatures of the generating system. This appears to offer substantial survival advantages to camouflaged installations. The SPFC offers similar advantages for powering unmanned reconnaissance aircraft, where reduced detectability is extremely important.

As air quality becomes an even more significant issue over the next few decades, the pollution-free, or at least low pollution, properties of fuel cell systems will offer market advantages over competing technologies -- whether it is SPFC's in vehicles or phosphoric acid, solid oxide or molten carbonate fuel cells in coal powered utility plants. The exact economic premium society is willing to pay for cleaner air is unclear at the moment. It is clear, however, that the premium differs from location to location and is increasing with time. Ballard Technologies believes that substantial markets are now opening up in such diverse areas as Sweden and southern California for clean, or at

least cleaner, power systems. These opportunities must be pursued aggressively by those wishing to promote the use of fuel cells.

c) **Mission Enabling Technology**

New markets are always created by substantial new technologies which permit activities which were previously impossible. The development of the transistor and its miniaturization to the chip have spawned thousands of new products and service industries. Many of these products and services could not have been foreseen before the enabling technological developments took place.

Ballard Technologies believes that fuel cells, and particularly SPFC technology, offers the potential for such a market explosion. We are actively pursuing applications ranging from the powering of advanced unmanned mine-detection and counter-measures vehicles to the powering of artificial hearts. In the absence of the SPFC and the performance that Ballard Technologies has recently demonstrated, these applications are difficult or perhaps even impossible to achieve.

Clearly in markets in which there is no established competing technology the price the market will support will depend upon the value ascribed to the newly available product or service. In the military and medical areas, substantial value is often placed upon new capabilities. These and other such markets can be substantial for emerging fuel cell technologies.

2) **LACK OF INFRASTRUCTURE**

Even when the cost issue has been set aside, there are other factors which inhibit fuel cell commercialization. The fuel infrastructure is the most obvious, but the interfacing of a DC fuel cell to an AC world and the creation of marketing and service support systems are no less significant.

In their simplest forms, most fuel cells operate on hydrogen and oxygen. While oxygen is readily available from the air (and, with the exception of the alkaline fuel cell system, readily used by fuel cells), hydrogen is not readily available. This leaves fuel cell advocates with the problem of either creating an infrastructure which makes hydrogen readily available to all potential customers or of creating an interface between the existing fuel infrastructure and the fuel cell. In reality, both approaches must be pursued.

<u>Current and Future Hydrogen Availability</u>

While many of us believe that hydrogen will become a significant energy currency in the next century, there are markets today for fuel cells running on hydrogen. Many military and aerospace applications have available or can justify the provision of gaseous or liquid hydrogen. Several industries either generate

hydrogen as a by-product (chlor-alkali, ethylene) or consume substantial quantities for other purposes (petroleum refining, ammonia production, metallurgical processes, electronic device production). Each of these applications represents an opportunity for fuel cells in which the fuel infrastructure is essentially in place. Unfortunately, these examples represent a small fraction of the potential for fuel cell applications.

Governmental action is often required to create an infrastructure which is driven by societal needs rather than immediate economic benefit. This is an appropriate activity of government. US governmental action was required to reduce the lead content in gasoline to protect public health. More recently, the Swedish government has passed sweeping legislation which places very heavy "pollution taxes" on diesel fuel and which will soon add equivalent taxes to gasoline. Revenues from these taxes will be used to fund the creation of hydrogen infrastructure development projects, such as the conversion of city busses from diesel to hydrogen.

Similar programs by the governments of the US, the EEC, and Canada will be required for the creation of an expanded hydrogen infrastructure. In addition, governments, universities, and industry should increase support for advanced research into hydrogen production, transportation, and storage.

Interfaces to Existing Fuel Infrastructures

The fuel cell industry cannot, however, wait for the Hydrogen Economy. Fuel cells must be integrated into the existing fuel infrastructure as well.

The existing fuel infrastructure is complex and multifaceted. In some areas, coal is readily available for fueling utility plants. In other areas, petroleum and natural gas are available. Gasoline and diesel are universally available for transportation fuels and, in some locations, propane and natural gas are also available. Methanol is just now becoming available as a transportation fuel, particularly in air quality sensitive areas such as southern California and Colorado. Either natural gas or fuel oil is available in most areas for space heating requirements.

The difficulties involved in interfacing fuel cells to these fuels varies dramatically depending upon the fuel cell and the fuel. The high temperature fuel cell systems (molten carbonate and solid oxide) are being developed specifically to use common fuels directly. At the high temperatures employed in these systems, the conversion of coal gas or natural gas into a useful form may take place within the fuel cell itself. In order to achieve this interface with the existing fuel infrastructure, the high temperature fuel cell systems have incurred the difficulties of achieving chemical and mechanical stability at high temperature. They are also practically limited to large fixed-site

installations in which the high temperatures can be safely controlled and the high temperature waste heat effectively used.

The low temperature fuel cell systems, the Phosphoric Acid Fuel Cell (PAFC), the Solid Polymer Fuel Cell (SPFC), and the Alkaline Fuel Cell (AFC) use a hydrogen containing gas as the fuel. This requires a separate reformer to convert the available fuels to hydrogen (and, in the case of the AFC, a system to extract very pure hydrogen from the product gas). While the chemistry of these processes is well known and used in many industrial applications, the technology for producing small, efficient reformers for small or portable applications is in its infancy.

A number of 40 kW PAFC systems have been delivered to utility companies for evaluation. The one evaluated by BC Hydro in Vancouver included a natural gas reformer. While BC Hydro is extremely pleased with the efficiency and reliability of the system, they point out that the fuel cell occupies one half of a trailer while the natural gas reformer occupies the other half.

With the new SPFC technology, a Ballard Technologies 40 kW fuel cell stack only occupies 4 ft^3 (0.11 m^3). This significant reduction in stack size will permit new applications for fuel cell power sources, provided fuel processing systems of comparable size and efficiency can be developed. This will be more easily accomplished using methanol as the fuel than using hydrocarbon fuels such as diesel or gasoline. For this reason, Ballard Technologies and others are pursuing improved methanol reformer technology as the most likely method for providing fuel cells for near term transportation applications. The development of an improved reformer for natural gas would significantly enhance the prospects for fuel cell applications for small fixed site power sources and maybe even automobiles.

We would encourage a substantial investment by governments, industry, and universities in the creation and development of improved devices for the efficient transformation of currently available fuels into hydrogen. The performance and cost of fuel cell systems operating within the current fuel infrastructure will generally be limited by the properties of the reformer.

3) RISK AVERSION OF POTENTIAL CUSTOMERS

Even when a fuel cell system is no more costly than competing technology or when other factors yield a cost/ benefit analysis favorable to the selection of a fuel cell system, it is difficult to convince the potential user to purchase the fuel cell system. This is due, in large part, to the risk aversion mentality which most North American and European companies instill in their middle and even upper managers. Unless the competition is already doing something new or is clearly planning to do so, there is little benefit to the decision maker's career in selecting "new" and "untried" technology with its attendant

risks. This is particularly true if the potential pay-off is several years in the future.

The decision maker can rationalize risk aversion by pointing out a lack of data to permit the determination of life cycle costs (particularly lifetime, long-term operating and maintenance costs) and other data readily available to the decision maker for established technologies.

This represents the classic "Catch 22" for new technologies or old technologies in new applications. The product cannot be sold without extensive field-performance data and the extensive field data cannot be obtained without extensive sales. This problem is particularly significant for small companies, which often create new technologies, in that neither the product nor the company has an extensive track record.

The situation for fuel cells was summarized several years ago by a DND official who said that "the only thing SPFC technology needs is an order." Significant advances have been made since then in SPFC and other fuel cell technologies and still today, Ballard Technologies would put it that "the only thing fuel cell technologies need today are substantial orders."

This is, perhaps, an appropriate arena for governmental action--the encouragement of the adoption of new technologies. That encouragement can take the form of government and joint government-industry sponsored demonstration projects. It can take the form of tax or other governmental incentives to encourage private industry to adopt fuel cell technology. Finally, governmental encouragement can take the form of direct purchases of new technology.

Ballard Technologies continues to receive encouragement from the Canadian federal government in the form of R&D support from DND and EMR. We have also received encouragement from the province of Ontario through its Ministry of Energy in the initiation of demonstration projects. We look forward to the possibility of quantity purchases of fuel cells from DND. But, a substantial order from an "opportunity sensitive" company would truly put fuel cells on the road to market success.

4) DIFFICULTIES OF FINANCING FUEL CELL COMPANIES

Perhaps the greatest problem fuel cell technology faces is the survival of the companies, or divisions within large companies, which develop and pursue fuel cell technology. In the absence of established markets, fuel cell companies must rely on government R&D funds or rather expensive equity capital to survive and to pursue market opportunities. Fuel cell divisions of large companies are often required to pay their own way by subsisting on government study contracts. These contracts can become the raison d'etre for the fuel cell division rather than the production of fuel cells and the development of fuel cell markets.

Ballard Technologies certainly accepts government R&D contracts and will continue to do so. Ballard Technologies has accepted outside equity investment and will continue to seek such investment. But Ballard Technologies is seeking to break out of the fuel cell "Catch 22" by creating a consortium of potential fuel cell users who will share, and thus minimize, their risk of developing and demonstrating fuel cells for specific applications. In return for continued funding, an industrial sponsor will receive a product developed for its specific application, continued improvements in the core SPFC technology, and market exclusivity for its specific application.

We believe that this involvement of the potential user of the technology in conjunction with government sponsored demonstration projects and government-assisted infrastructure changes will provide the vehicle for the development of a substantial fuel cell market in this decade.

STATUS, FUTURE AND STRATEGIC APPLICATIONS OF FUEL CELLS

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The fuel cell program in the United States has arrived at a turning point in 1988. Going back ten years to 1977, a major milestone was reached for electric utility fuel cell design and development with the successful test of the 1 MW United Technologies Corp. (UTC) phosporic acid fuel cell (PAFC) demonstrator in South Windsor, CT. This unit, intended as the precursor of the 4.5 MW (ac) plant to be demonstrated in New York City, used 3.7 ft^2 cells operating at 50 psia pressure at 190°C. The temperature was chosen to allow satisfactory operation at the carbon monoxide levels present in reformed light fuels after two stages of water-gas-shift, bearing in mind that the cell stack was required to operate at a sufficiently high temperature to produce high-pressure steam for the reformer. This requirement was necessary so that reformer steam could be provided by fuel cell waste heat, giving higher overall system efficiency (based on system operating parameters, this was to be be about 37% of the higher-heating-value of the light hydrocarbon fuel used). Additionally, less than 80% of the hydrogen produced in the reformer could be effectively used in the cell, so the anode exit gas stream was burned to provide the heat of reforming. However, based on the higher-heating-value of hydrogen, efficiency of hydrogen fuel actually used in the cell was about 44%.

The cells contained composite one-piece cross-flow polysulfone-graphite molded bipolar plates, which were shown to have inadequate corrosion resistance during the course of the test. Low-loading carbon-supported platinum electrodes were used, with approximately 3.6 g/kW of platinum at the rated power density of 211 mW/cm^2. This represented a catalyst cost of $60/kW at present platinum prices. Experience showed that evaporation of electrolyte would be a problem over a five-year lifetime. Since it was considered that replenishment of the electrolyte would be unreliable, a reservoir would be fitted in each cell. This reservoir plate was derived from the alkaline space-shuttle fuel cells, and was first fitted to early 40 kW on-site fuel cell units, which were followed by the 4.5 MW Tokyo Electric Power Co. demonstrator (ordered 1980, operated 1983-85).

All UTC units used pressurized water evaporative cooling with teflon-coated copper-tube flash-steam heat-exchange piping in cooling plates, which were arranged every five to eight cells. As indicated above, the steam thus produced was directly supplied to the reformer. Other U.S. developers adopted liquid dielectric cooling with similar plates (Engelhard Industries), or air cooling using specialized cooling plates. The latter was used by Energy Research Corporation and its licensees, Sanyo and Westinghouse. In its earlier and simpler versions, the latter used process air cooling in a variant known as DiGas^R.

Up to 1987, PAFC systems had not progressed much beyond the descriptions given above, except for a scale-up from 3.7 ft^2 to 10 ft^2 stacks in the proposed 11 MW PC-23 unit to be marketed by UTC (which became International Fuel Cells, IFC, in a joint venture with Toshiba). This scale-up involved an increase in system pressure from 50 psia to 120 psia, with a concommitant increase in temperature from 190°C to about 210°C. This increased cell voltage, therefore efficiency. To maintain an end-of-life voltage of 0.73 V (corresponding to 42% HHV system efficiency, up from 0.65 V in the early demonstators), current density was reduced to 216 mA/cm^2. This higher voltage, with cells operating at higher temperature and pressure, implied a better knowledge of materials problems at the oxygen cathode, which had hitherto limited further increases in performance In turn, this resulted in the use of all-graphite system components.

Apart from the increase in operating conditions, some of the more interesting concepts within the last five years have been new types of stack design, which potentially permit lower cost. These have included the "Hybrid Stack" of Toshiba, which is a compromise between the graphite ribbed bipolar plate design in the UTC 4.5 MW demonstrator on the cathode side, and a ribbed substrate system with an anodic electrolyte reservoir plate. Equally interesting are the Engelhard ABA concept, the Kureha KES-1 bipolar plate, and the "Configuration B" IFC design. These should allow lower cost by the elimination of a flat graphite bipolar plate between the porous graphite ribbed cell substrates, which in some cases also serve as electrolyte reservoir plates.

The PAFC still has the potential for cost reduction and increase in efficiency. Still, all is not well in regard to its potential market, at least in the United States. Its initial cost is much too high for normal electric utility applications, and the building-block unit prosed by International Fuel Cells (the 11 MW PC-23) appears to have a limited market appeal. Small utilities would appear to prefer a unit of 2-3 MW, whereas large utilities in big cities (such as Consolidated Edison in Manhattan) would prefer units of as much as 100 MW in

size. In addition, the unit was designed for maximum accessibility from the maintenance viewpoint, and it has a power footprint of 3.7 ft^2/kW. For use on restricted sites in large cities, 0.43-0.78 ft^2/kW will be necessary. HHV efficiency can probably be increased from 42% to perhaps 47% by incremental systems improvements and an increase in operating pressure and voltage, but system life (limited by cathode corrosion) may then pose limitations. Cost can undoubtably be reduced, specifically by introducing the "Configuration B" design, which is already used in the 200 kW on-site cogeneration unit. Approximately 70 units of the latter are on order or on option, and the cogeneration application appears to provide a better market, better energy utilization offsetting higher unit cost per electrical kW.

Far better prospects are likely for the on-site molten carbonate system, particularly in its internal-reforming variant, the IRMCFC. The potential capital cost of the IRMCFC, together with its unprecedented efficiency, development potential, and flexibility from the viewpoint of efficiency versus capital cost, should make it a formidable competitor in the energy marketplace. However, for the cogeneration application, it will be limited to a heat/power ratio of about unity. This heat/power ratio is also relatively inflexible (as it is for a gas turbine, and less so for a steam cycle). A question that should be addressed is how the IRMCFC will compare with a gas turbine in the cogeneration mode, e.g. for a heat/power ratio of 2.4. In this case, the IRMCFC will have to operate with an auxiliary furnace (costing about $80 per kWe to provide $2 per kWth). If the fuel cell cost is as low as has been discussed above, the combination should be competitive with the gas turbine and will also have the merit of being more flexible, since the heat/power ratio can be changed at will. If only space heating (or industrial mechanical vapor recompression) is required, a combination of the on-site MCFC fuel cell with a heat pump should be unbeatable.

Using a reasonable $650 per kW estimate of system cost (either external-or internal-reforming), an electricity cost analysis has been conducted comparing various stand-alone electric-utility MCFC systems to conventional coal and natural gas plants for baseload and part-load use. The results show that the MCFC should be competitive with conventional coal for baseload use if a credit is taken for lower transmission line costs and energy losses when dispersed generators are used. For intermediate duty use, small (3.25 MW) IRMCFC generators (with dispersed power credits) will produce cheaper electricity than 60-MW combined-cycle systems. We must also emphasize that the comparison is between immature and mature technologies; the IRMCFC has growth potential to efficiencies of 71% or

greater, as further problems are overcome, and as knowledge of the electrode processes increases. Similarly, as stack lifetimes are improved, projected operation and maintenance costs of the MCFC will become lower. Finally, when the MCFC technology has been proved in small units, it may become the technology of choice for use with coal-gasification combined-cycle plants, for which efficiencies of 55% can now be predicted with negligible emissions (under one ppm NO), when cell results used in earlier studies are corrected to the best pressurized cell data. The MCFC is an electric power generation technology for the 21st century that energy planners cannot ignore.

The future of the tubular SOFC design is more difficult to predict. It is likely always to be less efficient than the MCFC, and if costs are equal, the latter will therefore be preferred. It is presently unknown whether the tubular SOFC can be made in large units or can be operated under pressurized conditions. In contrast, the planar "monolithic" SOFC should be very attractive as an energy conversion device for many future applications, provided that it can be made at an attractive cost. Its light weight, small size, and very low materials cost per kW may make it attractive for transportation applications, for which the MCFC is not suitable. For example, it could advantageously find use in automobile transportation using methanol fuel with internal reforming. Bringing it up to operating temperature for this application will present problems, even if it thermally cycles well, its fuel-efficiency would be poor on short trips because of the energy requirement for reheating after a cool-down cycle. It may therefore be attractive only when hybridized with a battery, which would serve for short-range use and for regenerative braking. If and when hydrogen eventually becomes widely available as a fuel, the advantage of the monolithic SOFC's ability to use hydrocarbons or methanol will diminish. The cold-starting capability, equal efficiency and low operating temperature of an advanced AFC may then make it the most attractive transportation power source, especially bearing in mind that it would require no precious metals. In contrast, the solid polymer acid system would probably find only specialized applications.

Coal gas fuel systems have been mentioned above. However, by the time that these are ready for operation, the greenhouse effect may have made systems dicharging carbon dioxide into the atmosphere unacceptable. If this should be so, the carbon dioxide must be first separated from the coal gas and disposed of, for example in oil and gas wells, coal mines, or in the deep oceans. Again, the alkaline system may be the first choice in this application.

FUEL CELL WORKSHOP:

POTENTIAL OPPORTUNITIES IN CANADA

Toronto, April 28, 1988

FUEL CELLS AT HYDRO-QUEBEC:

REMOTE AREAS

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APRIL 1988

1. INTRODUCTION

Canada is in a rather unique situation in terms of providing electrical energy in remote small communities in harsh climate. This situation is shared by Russia and to some extent in the Scandinavian countries. The magnitude of the electrical demand in Canadian remote areas is of the order of 1,4 TWhr per annum (the Québec's global demand is of the order of 100 TWh/ annum). The power levels are very diversified ranging from a few kW to the multi MW range. In Table I and Fig. 1, we present the different pertinent parameters: these data were obtained from a EMR (1) report and were updated in some instances from data obtained from utilities (2).

The vast majority of the electrical demand is provided by generator coupled to diesel motors. The cost of the electrical power so produced is far in excess of the one available to custommers linked to major provincial network. The high cost is associated to essentially three factors:

+ the fuel cost and mainly its transportation cost,
+ the limited efficiency of a diesel generator,
+ the high cost of maintenance.

Several alternatives have been / or are under evaluation. The first is to use indigenous renewable resources for electrical generation. These resources could be wind energy, wood, solar energy or small hydro dams. The conservation of energy is also promoted but given the context, is sometime difficult to put in practice.

In this presentation, we will review the electrical situation in two specific locations in Québec, Blanc Sablon and Povungnituk.

We will consider the limit and potential of using fuel cell as a direct energy conversion device to generated the electrical demand with a high efficiency. To use fuel cell, a proper fuel must be available: the basic fuel to power a fuel cell is hydrogen. This primary fuel cannot be shipped

to remote areas because of its low energy density by volume as well as its difficulty in handling, storage and security. The standard procedure is to generate hydrogen via a steam reformer from a fossil fuel. Two advantages can be identifed: the fuel can be liquid and the technology for such process is available. However, the reformers for fuel cell based on liquid fuel (naphtha) have been developed only for large multi-megawatt units. For smaller units, only natural gas reforming has been developed.

2.1 REMOTE AREA, GENERAL DESCRIPTION

Canada, because of its geography (human and physical) has a large number of communities isolated for the main electrical provincial networks. The number of such isolated communities has been determined in a federal study (1) and is evaluated at 359. Table I gives the geographical distribution of these localities. As seen in this table, British Columbia has the greatest number of such remote sites.

The other characteristic of these locations is the range of population and, by consequence, the range of electrical demand resulting. The range induces a wide range of installed capacity. The smallest generating station could be as low as tens of kW and the largest in the multi MW range (White Horse in Yukon with 72 MW of installed capacity).

The other aspect associated with remote area is the difficulty and cost of providing fuel in these localities. The shipping is varied and includes maritime transport in limited time period (summer), air transport or trucking the fuel to the location. The sporadic nature of fuel provision induces extensive storage of the fuel on site.

One other difficulty is associated with the operation and mainly maintenance of the generation station. For some utilities responsible for the provision of electricity in these areas, the maintenance crews are located in cities in the south and are airborne to provide overall maintenance of the generation equipment. The local labor is used for the day-to-day operation.

Because of the remote locations and its mode of tranportation, the fuel must have a high energy content specially in terms of volume. This criteria limits to liquid fuel the type of primary fuel needed in these locations. The fuel now used is diesel fuel or artic fuel. This fuel is used for electrical generation, but has the advantage of being used for other purposes (land or marine traction and direct heating).

2.2 LOCAL SITUATION

We will briefly describe the situation in two remote localities under Hydro-Québec's responsability. The first one is on the lower north shore in Blanc-Sablon. In Fig. 2 to 4, we present the different parameters associated with the electrical demand and the oil consumption for electrical production.

In Fig. 5 to 7, the data for an isolated village on the Hudson Bay are presented namely for Povungnituk. In both cases, the trend is towards an increased electrical demand mainly because the price paid by the consumer is not linked to the production cost of the electricity. For Hydro-Québec, this situation leads to a deficit of 0,149 $ and 0,311 $ per kW in the lower north shore and New Québec area respectively. In 84-85, this situation led to a 14 M$ annual deficit for these two areas. In this evaluation, we did not include the major remote site on Hydro-Québec's network, namely Iles-de-la-Madeleine in the Gulf. For this site, a deficit of 16,3 M$ in 87 was registered.

The cost of fuel in remote areas is a major burden: for example, on Québec lower north shore, the fuel cost corresponds to 0,118 $ / kW on a production cost of 0,194 $ (61%); in New Québec, the fuel cost lower in the production cost (51%), the operating and maintenance cost being the predominant factor. For this area, the total production cost is 0,405 $ / kWh.

As we see, the economics of the electrical production and distribution for a network like Hydro-Québec is important. To reduce this deficit several measures are implemented: an improvement on fuel conversion efficiency brings a direct benefit. As seen in Fig. 7, such improvements are implemented in Povungnituk: this is achieved by combining different sizes of diesel to operate the system at its peak efficiency: combining small units for low load and using larger ones only when the load is sufficient.

A second alternative, also used, is to rely on new renewable energy sources. To this effect, an experimental program is underway whereby a windmill is coupled to a diesel system and acts as fuel reduction system. When the wind and the demand is present, the diesel operates at reduced or minimal output. This system is under test at Kuujjuaq on the Ungava Bay.

Up to now, fuel cells were not considered due to their experimental status and also based on the gaseous fuel needed (methane).

3. REFORMING TECHNOLOGIES

The analysis was performed on the basis of different nominal capacity of hydrogen production to operate a fuel cell power plant. The AC power output was set from 200 kW to 6 200 kW and the hydrogen flow rate were calculated with the following provision. The efficiency of the conversion of the hydrogen energy content into AC electric power was set at 46% (based on results obtained at IREQ on a 40 kW fuel cell power plant) and a 5% excess was integrated into the energy balance to allow the anodes to be in a reducing atmosphere as specified by the fuel cell vendor. In Table I we present the calculated data. The energy of the combustion is based on the lower heating value of hydrogen, namely the following reaction:

$$H_2\ (g) + 1/2\ O_2\ (g) \text{ ----- } H_2O\ (g)$$

The minimal value is the quantity of hydrogen needed to maintain the fuel cell in a stand-by condition: it is essentially 30% of the nominal power plant capacity.

TABLE I

HYDROGEN PRODUCTION SCENARIOS

Fuel Cell Nominal Power (kW)	Hydrogen Requirement Minimal [m^3 (NTP)/h]	Maximal [m^3 (NTP)/h]
200	47	166
750	174	624
1000	232	830
6200	440	5146

The main source of industrial hydrogen nowadays, is via the steam reforming of natural gas. This process is used extensively by the chemical industry to produce hydrogen for synthetic purposes. The production steps include the steam reforming according to the following reaction step:

$$CH_4 + H_2O \quad \text{----->} \quad CO + 3\,H_2$$

This reaction is highly endothermic and, as such, needs a heat supply to bring the reformer at operating temperature and to maintain it at that temperature during the reaction.

The second reaction to obtain the complete conversion of methane to hydrogen involves the reaction of carbon monoxide produced in the reforming step with steam to generate hydrogen and carbon dioxide along the following reaction:

$$CO + H_2O \quad \text{----->} \quad CO_2 + H_2$$

This last reaction is known as the gas Shift reaction and is exothermic and the excess heat is usually used in the overall hydrogen production facility.

These reactions are carried out on catalytic beds: for the reforming, nickel based catalyst is used whereas an iron-chromium based catalyst is used for the Shift conversion reaction. In any chemical process, the gas is purified to be used down stream: in most cases, the purification process is aimed at removing the carbon dioxide and the traces of unreacted carbon monoxide. For the use in a phosphoric-acid-based fuel cell, this last step is not needed since the power stack is tolerent to carbon dioxide. The power stack is more sensitive to carbon monoxide and sulfur containing compounds: the sulfur removal is also critical for the life of the reformer catalysts. The sulfur removal in the fuel is achieved via a

hydro-desulfurisation unit whereby hydrogen gas reacts on a catalytic bed with the sulfur bearing molecules to produce hydrogen sulfide. This gas is then trapped on zinc oxide. The maximum sulfur content in the natural gas is for a typical fuel cell power plant in the range of 40 ppm for the planned 200 kW unit. For the 11 MW unit of IFC, the allowable limit is 100 ppm per volume in the feed natural gas.

The same scheme is applicable to other light (gaseous) hydrocarbons: propane, butane, naphtha and gazoline. The yield is best for methane and is reduced as the C-C chain is extended. The reformer temperatures have to be increased to follow the complexity of the feedstock.

Medium hydrocarbons (jet-fuel, heating fuel and diesel oil) are a good option for the hydrogen generation based on their availability, cost, ease of storage and polyvalence in the location of the production facility. However, up to now this hydrogen production system is only at the experimental stage. The main problem is associated with a catalysis deactivation in the reformer. This deactivation can be traced back to two phenomena: sulfur poisoning and carbon deposists on the catalysts with the concomittent deactivation of active sites. This carbon formation is favored with these types of feedstock due to the presence of aromatic hydrocarbons. The hydrogen deficiency of these compounds makes this carbon deposit more favorable. The solution considered for this problem is centered around two scenarios:

+ Increased hydrotreatment to hydrogenated the sulfur compounds but also to hydrogenate the aromatic fraction of the feedstock

+ Use of new catalysts more tolerant to sulfur poisoning and less susceptible to the complete dehydrogenation or carbon formation.

This last approach is pursued actively by Toyo Engineering Corporation of Japan: the catalyst used in this newly commercialized process is based on CaO and Al_2O_3. The process uses high temperature and is known as the HRTSR (high temperature steam reforming). The sulfur content of the produced hydrogen via this reforming process must be carefully controlled if the hydrogen is to be used in a fuel cell power stack.

The production using controlled oxidation of heavy hydrocarbons and even coal has been used in the past: the modern trend has been a shift from these processes towards the use of natural gas as a feedstock based on the simplicity of the process and the lower sulfur content of this latter fuel.

Finally, one ideal fuel for the hydrogen production for fuel cell application in remote areas could be methyl alcohol (methanol). This fuel is liquid for an extensive range of temperature (-94 to +65 °C). Its energy content is lower than a liquid hydrocarbon like diesel oil but could be adequate for that purpose; the total energy content of methanol corresponds to 4,9 kWh/L as compared to 10,5 kWh/L for a typical diesel fuel. On a volume basis, methanol is penalized. For the remote areas, this penalty is of the upmost importance because the fuel is shipped in limited periods with a limited shipping capacity. All things being equal, a methanol system would need 2,12 time more shipping capacity than diesel.

For the hydrogen production however, the reforming of methanol can be carried out more easely than diesel. The chemical purity and composition can be controlled more adequately than diesel oil and the operating conditions of the reformer are less drastic in terms of temperatures. Several experimental methanol reformers have been tested but this equipment is not an off the shelf unit.

The technico economic assessment of this option has not yet been carried out. This analysis will have to consider the potential gain in effeciency and to balance this gain with the superior cost of methanol and also the shipping and storage cost that could be superior.

4. CONCLUSION

The general conclusion that can be drawn from this preliminary analysis, is that electrical generation in remote areas is a real problem for Canada. In the present state of the technology, fuel cell is not an economic alternative. In terms of R&D, this situation could be improved specially in the development of more efficient reformer for diesel oil or methanol. The fuel cell technology cannot be developed for this unique application. For this application, Canadians will have to adapt existing technologies for that purpose.

5. HYDRO-QUEBEC'S INTEREST IN FUEL CELL

Since the creation of IREQ in 1970, fuel cells have always been an active area of research or demonstration. The research efforts have been focused on materials with a major concentration in the time frame 1970 to 1977. Since then, this research effort has been divided into fuel cell and water electrolysis materials. All along this period, the demonstration of the fuel cell technology has also been a major activity. In that respect, we may mention the testing of six 12,5 kW first generation of phosphoric acid fuel cells in Québec city in 1972. This demonstration activity was pursued in 1984 with the installation at Varennes of a modified 40-kW fuel cell from International Fuel Cell (formely United Technologies). This power plant is still operational and has been tested for Bell Canada and for Hydro-Québec.

In term of follow-up of the fuel cell technology, Hydro-Québec was a founding member of the Fuel Cell User's Group of the Electric Utility Industry (a US based organization). Hydro-Québec was a member of this group from 1980 to 1986. In 1983-84, Hydro-Québec was actively involved in the formation of a Canadian Fuel Cell user's group under the enthusiastic leadership of Martin Hammerli of the former Energy Division of the NRC. This project was not completed due to the disparition of the Energy Division in 84.

Our present interest is limited to a follow-up of the technology to be ready to install fuel cell in remote areas (specially at the Iles-de-la-Madeleine if the project to link these islands to the main shore does not materialize). A study for the CEA is now in its final phase and should be submitted in June on the reforming of liquid fuels for fuel cells in remote areas. The 40-kW fuel cell is on stand-by and its operation is pending on interest from either operational engineers of Hydro-Québec or an external client (EMR?).

For the long term, the use of the hydrogen cycle to store electrical

energy on a seasonal basis remains a potential use for fuel cell. For that application, the analysis indicates that a reversible fuel cell is a must (the same hardware acting as a fuel cell and an electrolyser) to achieve a viable system. For this application, we are dealing with multi mega Watts systems. No decision to support this type of activity has been put forward or been accepted for R&D support by Hydro-Québec's management: it is still a very preliminary research idea.

HYDRO-QUEBEC AND FUEL CELLS

RESEARCH (MATERIALS)

1970-

A. K. VIJH; THEORETICAL AND EXPERIMENTAL WORK

I. MORCOS; ELECTROCATALYSIS, GRAPHITE BASED SYSTEMS

J. P. RANDIN; TUNGSTEN BRONZES

G. BELANGER; ANODIC OXIDATION MECHANISM

DEMONSTRATION

1972

TESTING OF SIX 12,5 KW UNITS IN QUEBEC CITY

1984-

TESTING OF A MODIFIED 40-KW UNIT

PROMOTION

1980-86

THE FUEL CELL USER'S GROUP OF THE ELECTRIC UTILITY INDUSTRY

1983-84

MEMBER OF AN ADVISORY COMMITTEE OF THE NRC TO ESTABLISH A CANADIAN FUEL CELL USER'S GROUP

CONTRACTS

1985

BELL CANADA, 40-KW FUEL CELL EVALUATION

1987-88

CEA, FUEL REFORMING FOR FUEL CELL IN REMOTE AREAS

6. ACKNOWLEDGMENT

The authors express their gratitude to the personnel of the Montmorency region of Hydro-Québec responsible for the remote areas on the network. More specifically, our thanks go to G. Soulières (group manager), W. Dufresne, J. H. Hamel, G. Tessier, J. Anctil, G. Bourget, H. Bélanger, and A. Drolet. We wish to acknowledge the actve participation of the CEA contract monitor in providing additionnal data, namely M. Papic from B.C. Hydro and B. Seckington and R. Quick of Ontario Hydro. We greatly appreciated the diligency of E. Rodger of the Remote Community Demonstration Program of EMR in providing us the EMR study on the energy outlook for these areas. We would like to underline the financial support of the CEA in this study.

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1. Energy Overview Study of Remote Communities in Canada, Sigma Engineering Ltd, RCDP/PDCE-O, March (1985).

2. Fuel Reforming for Fuel Cell in Remote Areas, CEA report on contract # 548 G 529, to be submitted in June 1988 by Hydro-Québec.

REMOTE COMMUNITY DATA ANALYSIS

EMR DATA, CORRECTED

PROVINCE	NUMBER OF SITES	POP	ELECT. DEMAND MWH	INSTALL. CAPAC. kW	OIL FOR ELE. GEN. CU. M.	TOTAL OIL CU. M.	% OIL FOR ELC.
NEWFOUNDLAND	63	29218	90464	41062	28767	50540	57
QUEBEC	47	35535	493045	122030	148200	N.A.	N.A.
ONTARIO	42	15657	25336	12770	8697	13961	62
MANITOBA	14	10133	33138	79648	12399	18243	68
SASKATCHEWAN	10	3452	65592	4625	2605	4777	55
ALBERTA	8	6198	5476	3750	1987	3101	64
BRITISH COLUMBIA	91	25007	221769	74803	61957	539305	11
YUKON	22	22828	210852	105885	70095	125851	56
NORTH WEST TERRITORIES	62	44322	297594	119651	94513	211537	45
	359	192350	1443266	564224	429220	967315	410

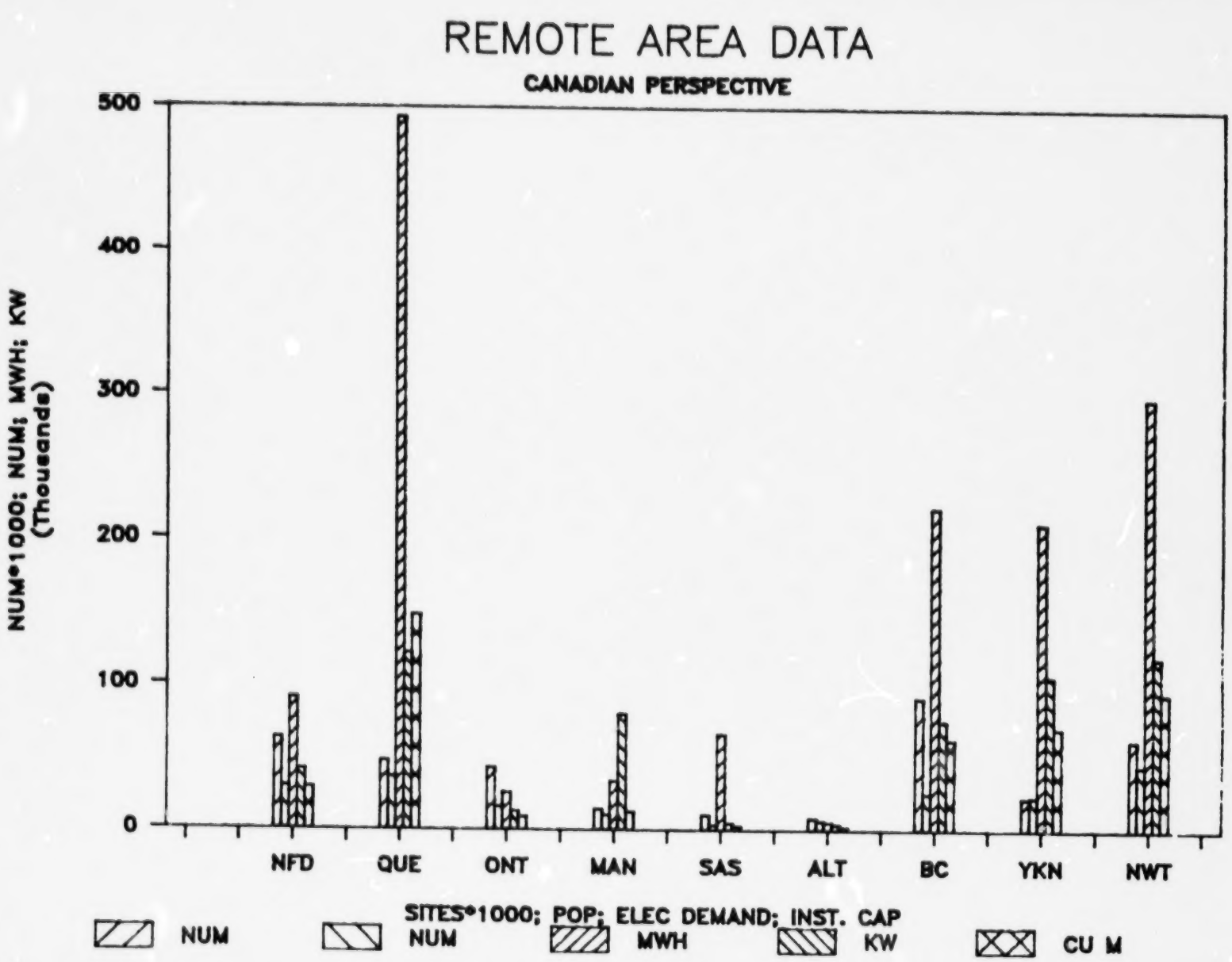

REMOTE AREA DATA
CANADIAN PERSPECTIVE
NUM*1000; NUM; MWH; KW
(Thousands)
500
400
300
200
100
0
NFD
QUE
ONT
MAN
SAS
ALT
BC
YKN
NWT
SITES*1000; POP; ELEC DEMAND; INST. CAP
NUM
NUM
MWH
KW
CU M

FIG. 1

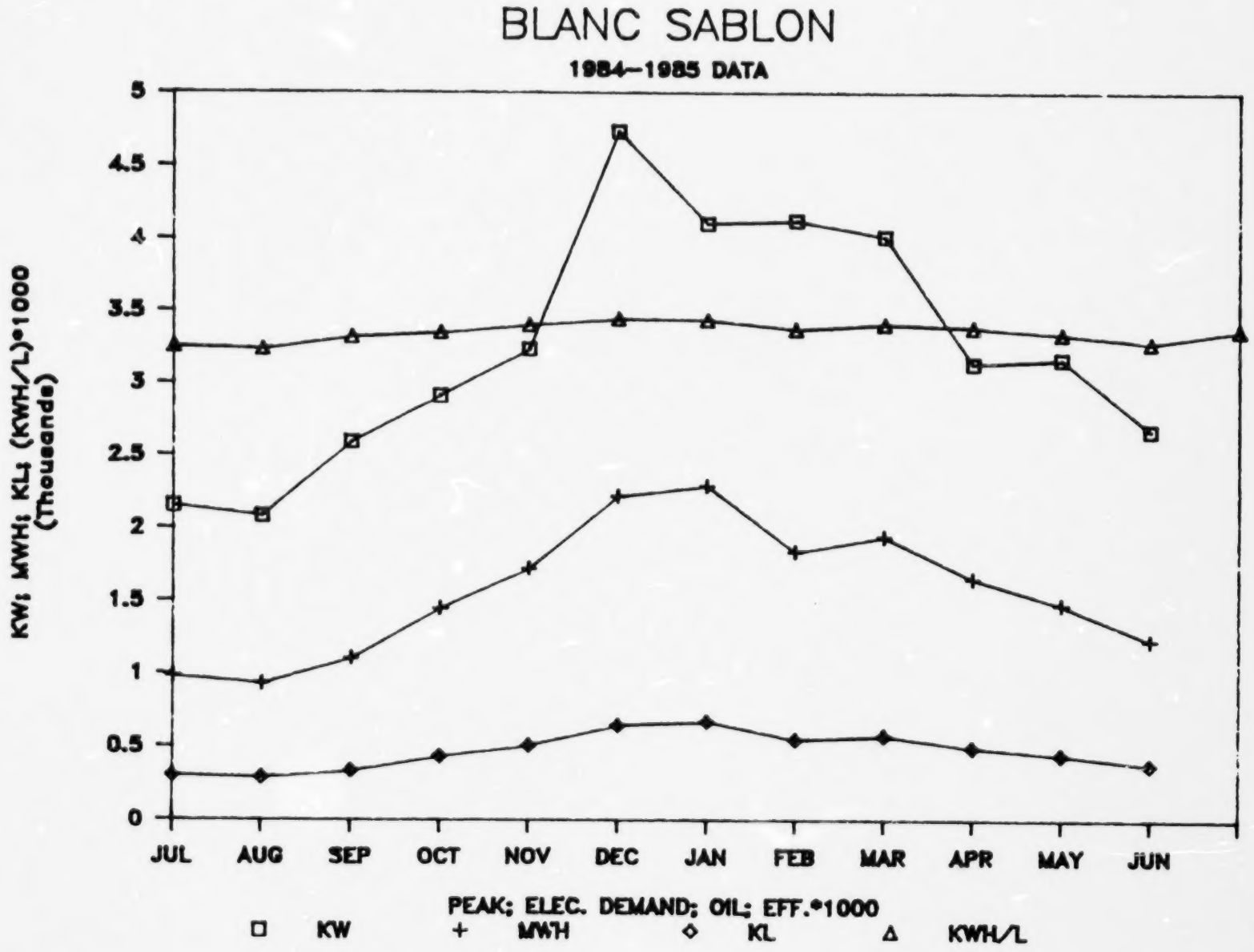

BLANC SABLON
1984–1985 DATA
KW; MWH; KL; (KWH/L)*1000
(Thousands)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
PEAK; ELEC. DEMAND; OIL; EFF.*1000
KW
MWH
KL
KWH/L

FIG. 2

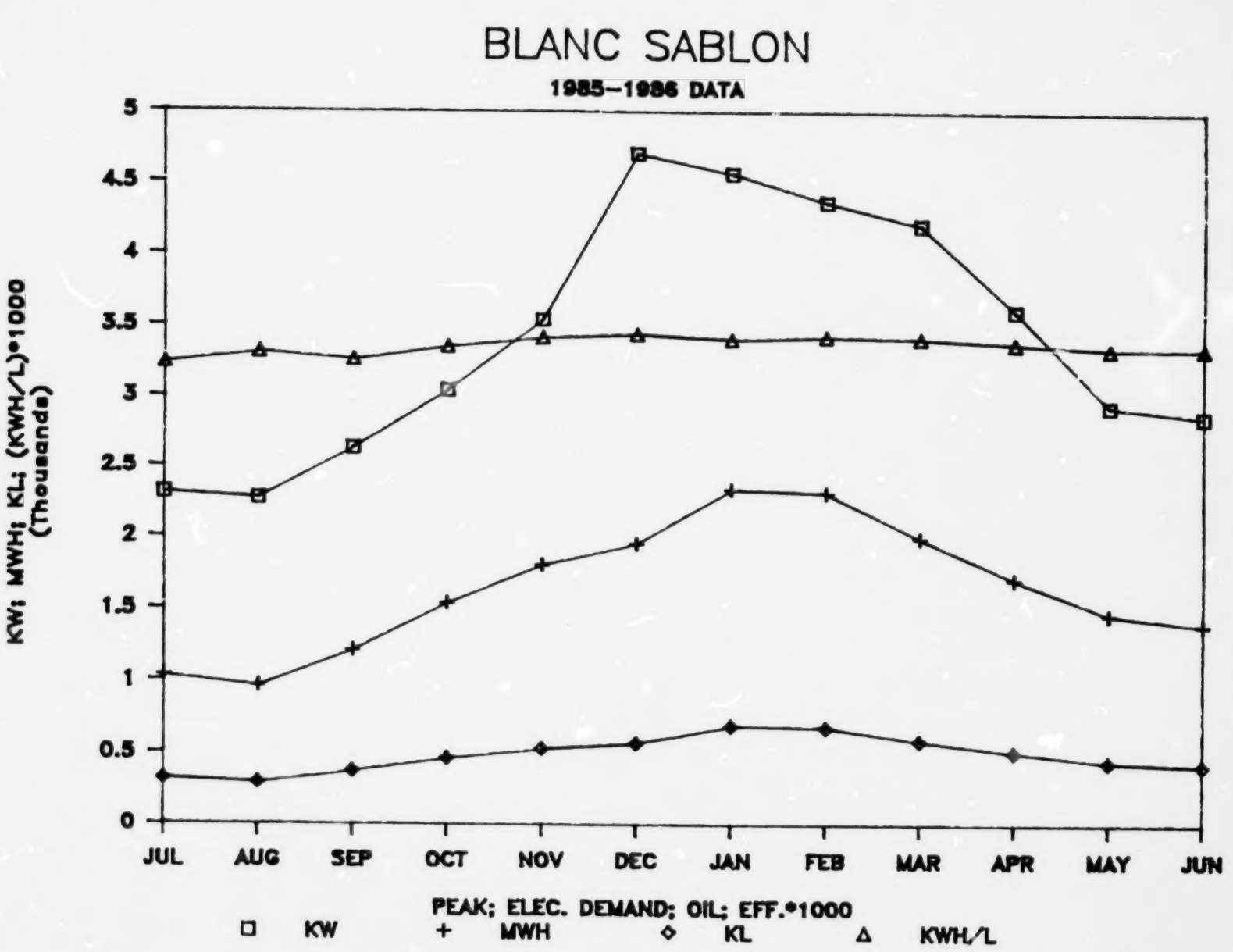

BLANC SABLON
1985–1986 DATA
KW; MWH; KL; (KWH/L)*1000
(Thousands)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
PEAK; ELEC. DEMAND; OIL; EFF.*1000
KW
MWH
KL
KWH/L

Fig. 3

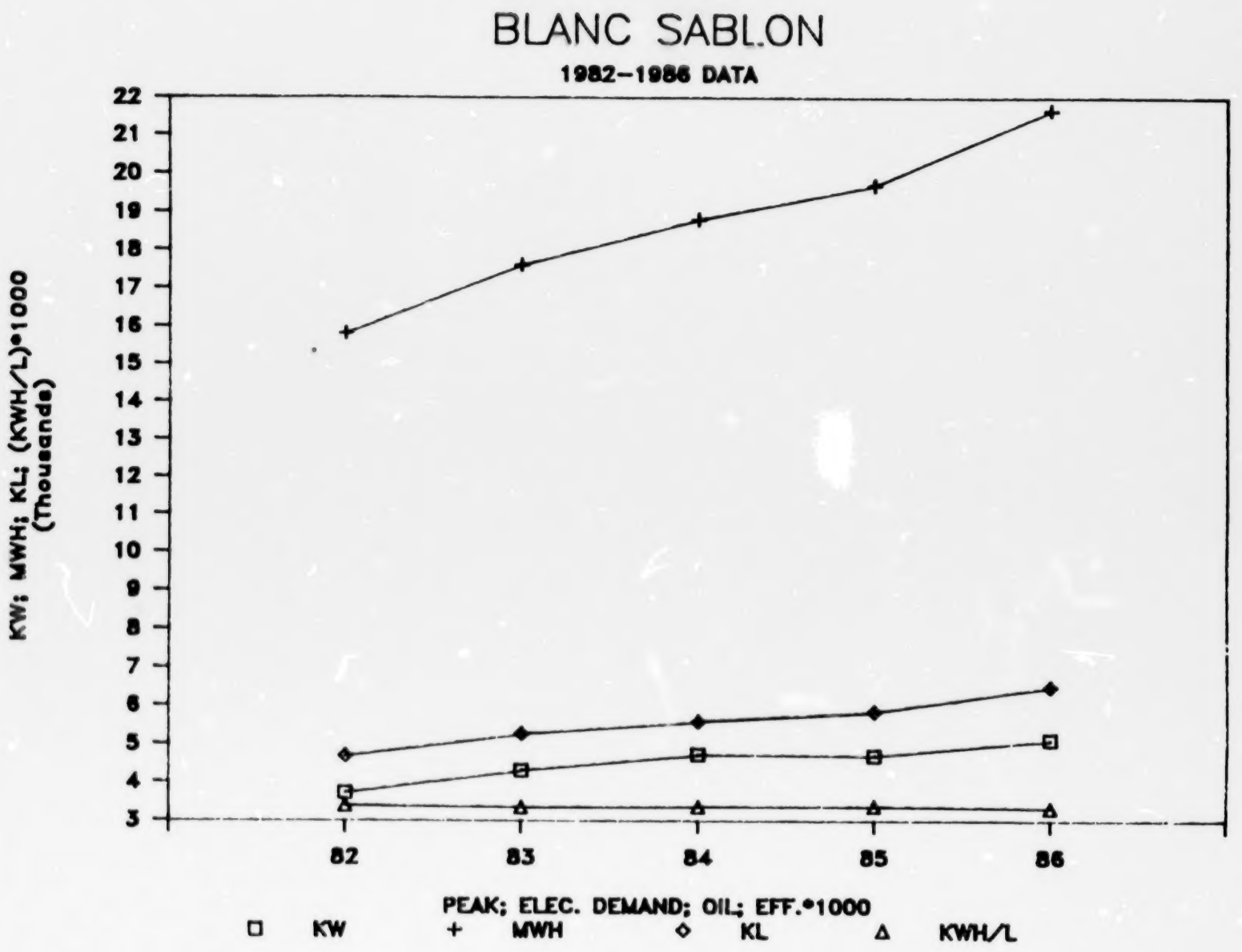

BLANC SABLON
1982–1986 DATA
KW; MWH; KL; (KWH/L)*1000
(Thousands)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
82
83
84
85
86
PEAK; ELEC. DEMAND; OIL; EFF.*1000
KW
MWH
KL
KWH/L

Fig. 4

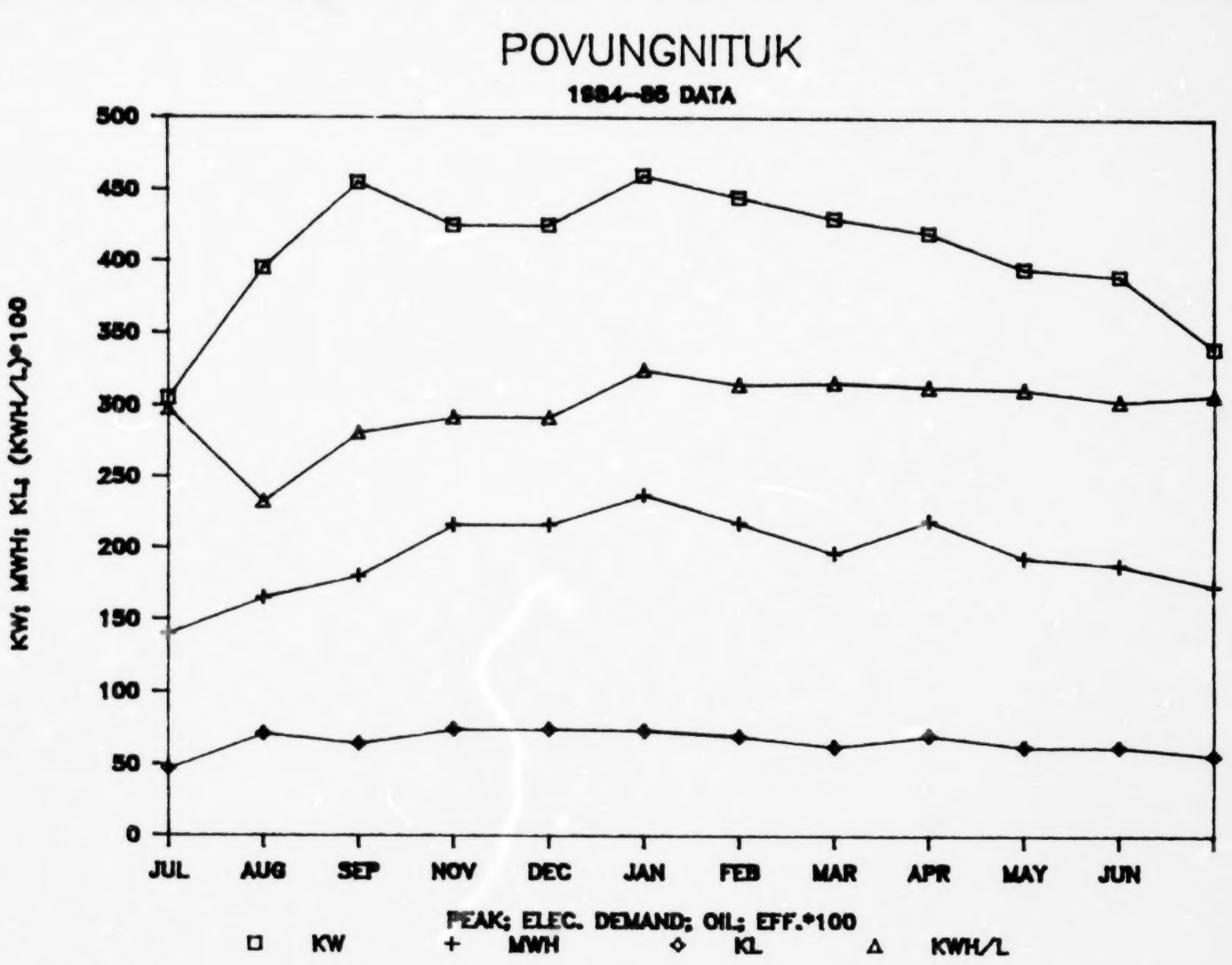
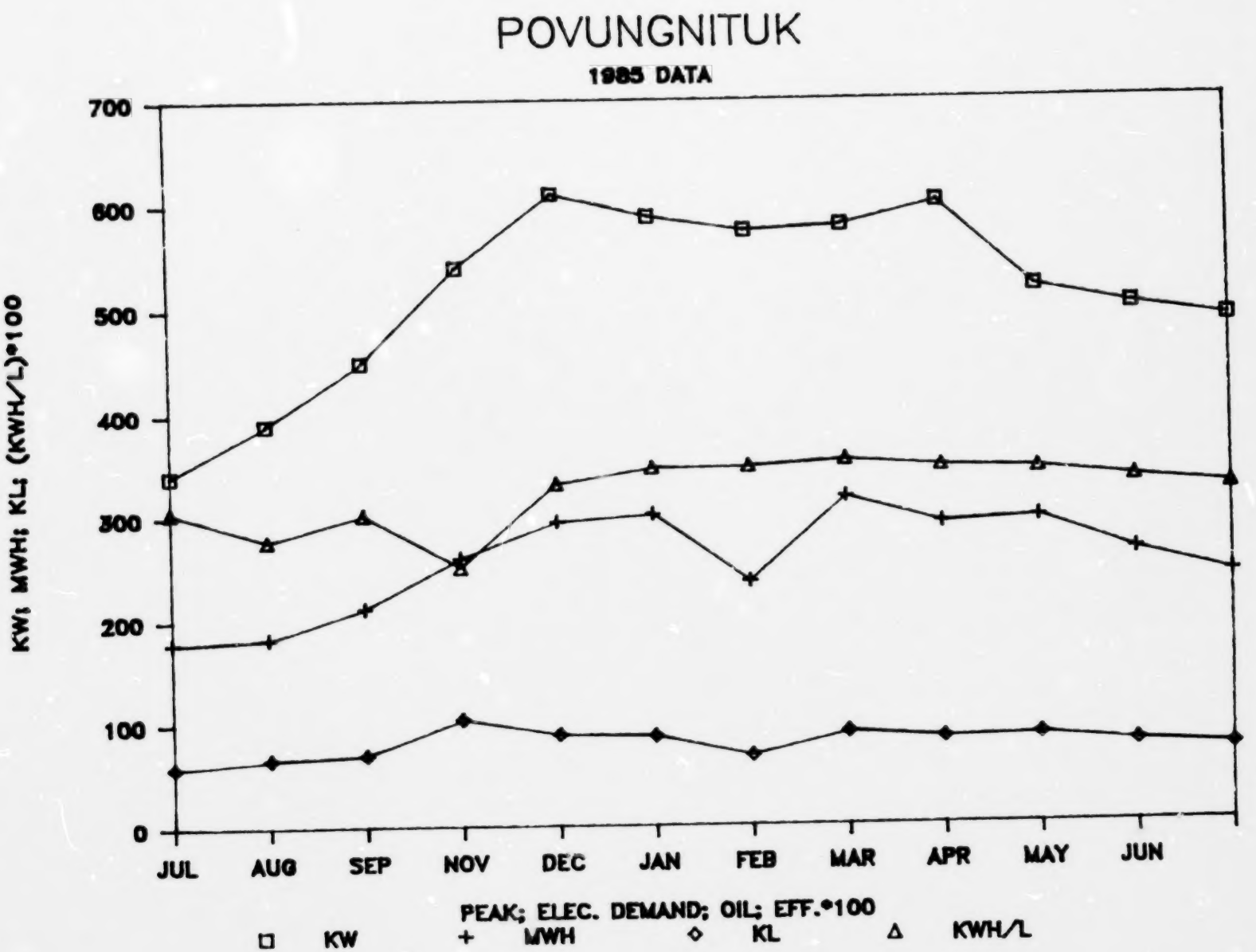

POVUNGNITUK
1984-85 DATA
KW; MWH; KL; (KWH/L)*100
500
450
400
350
300
250
200
150
100
50
0
JUL
AUG
SEP
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
PEAK; ELEC. DEMAND; OIL; EFF.*100
KW
MWH
KL
KWH/L

Fig. 5


POVUNGNITUK
1985 DATA
700
600
500
400
300
200
100
0
KW; MWH; KL; (KWH/L)*100
JUL
AUG
SEP
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
PEAK; ELEC. DEMAND; OIL; EFF.*100
KW
MWH
KL
KWH/L

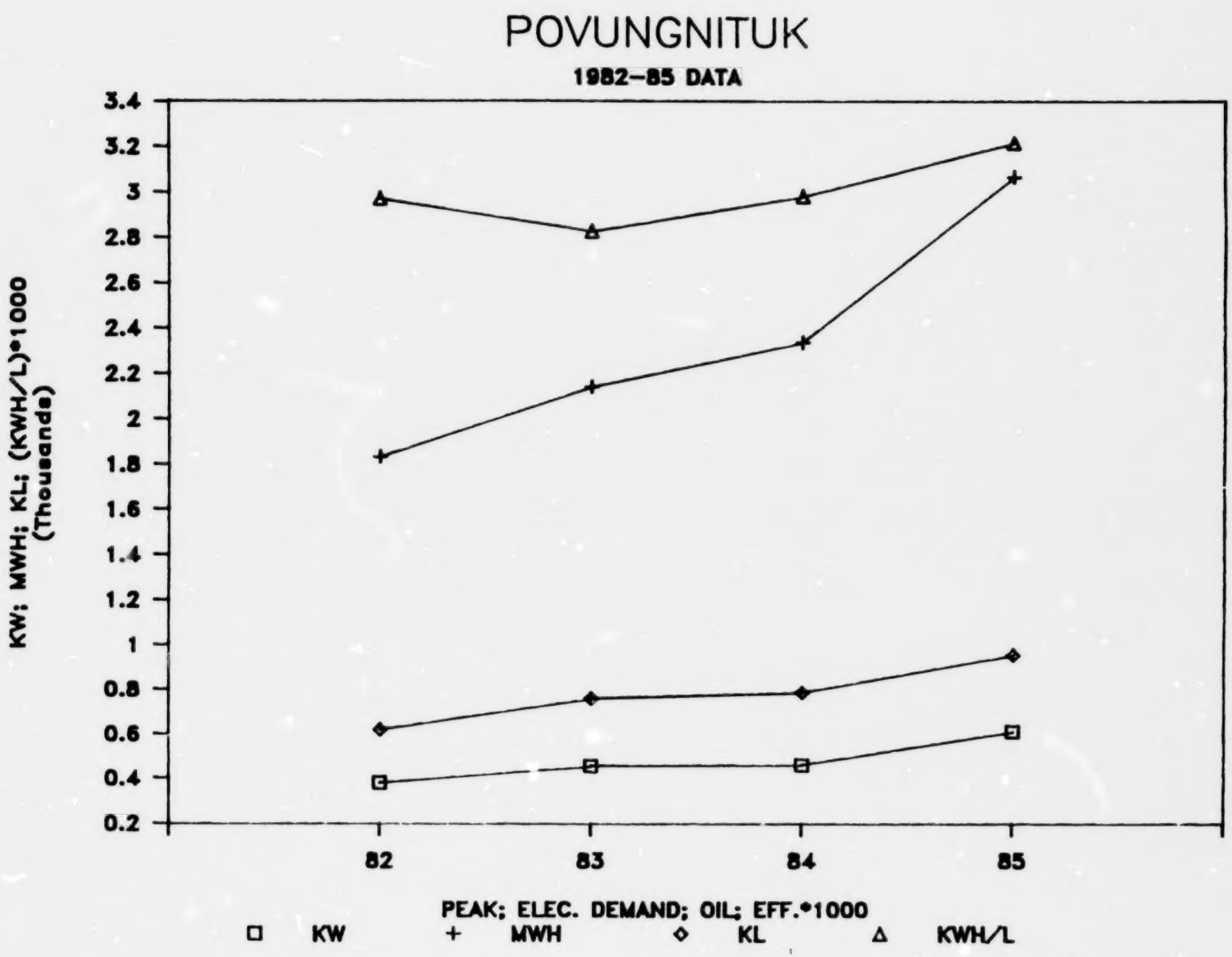

POVUNGNITUK
1982–85 DATA
KW; MWH; KL; (KWH/L)*1000
(Thousands)
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
82
83
84
85
PEAK; ELEC. DEMAND; OIL; EFF.*1000
KW
MWH
KL
KWH/L

FIG. 7

PARTICIPATION OF THE

HYDROGEN INDUSTRY COUNCIL

AT THE
ROUND TABLE OF THE
FUEL CELL WORKSHOP

Presented by
Richard D. Champagne

TORONTO

April 28th, 1988

POTENTIAL FUEL CELL OPPORTUNITIES IN CANADA

What's next?

The Hydrogen Industry Council tabled a year ago a Memorandum of Understanding with the Federal Government in which we identified fuel cells as a prime technology area where the Canadian Government should focus major efforts. Our recent study on fuel cells, where the essence of the findings were presented earlier by Dr. Crawford, was primarily conducted to identify partners in fuel cell demonstration projects in Canada. The rational for this thrust is the sense that the fastest and most effective means to generate the awareness, commitment, and financing for ongoing fuel cell development over the longer-term is to demonstrate under real life conditions, as soon as possible, the fuel cells that have already been developed in Canada. These projects would show that the cells perform as expected and required, thereby generating the credibility, and confidence necessary as a basis for commercialization and continued development.

In spite of currently tolerable conventional fuel prices, these projects should be mounted as soon as possible for several reasons including:

i) The inherent environmental advantages of fuel cells as quiet, non-polluting electrical generators;
ii) the competitive position of Canada among industrial nations and

iii) the likelihood of increasing conventional fuel prices within the 15-year lead time contemplated for the development and demonstration program.

Demonstrations could be mounted in the near term in sizes up to several kilowatts. Projects requiring tens of kilowatts should be possible with further technology development within the next 5 years or so. Larger projects in hundreds of kilowatts will take longer. The overall program is anticipated to span roughly 15 years with technology development occuring largely within the 5 to 10 year time frame and the prototype demonstrations within 10 to 15 year.

The implementation and success of the program depend on sustained commitment and collaboration of governements, primarily federal, in funding the demonstrations and private organizations in performing the work.

We recognize, that fuel cell development in Canada is a major challenge that will require considerable time and financial commitment. There seems a general sense of interest to get on with the job and an implied willingness to participate in such developments, assuming the necessary commitments of resources, both public and private, is made.

Let us now look at the proposed development and demonstration of fuel cells in Canada.

The greatest expressed interest is :

i) portable generators, 5 to 10 KW and

ii) mobile generators including submersibles 10 to 50 KW. Demonstration of these types could presumably be mounted in a reasonably early time frame.

While utilities favour:

iii) fuel cell power plants for cogeneration and remote communities, 25 to 1000 KW. Options here are development of large alkaline fuel cells, importing phosphoric acid fuel cells from the U.S. or waiting for molten cabonate fuel cells or solid oxide fuel cells.

To determine which projects are to be undertaken they would first be reviewed by two committees of the H.I.C., the Scientific Research Committee and the Steering Committee of Development. These committees in fact will have representatives who would participate in various ways in fuel cell implementation, notably including the organizations engaged in fuel cell development, government departments necessarily involved in their funding and the end-users of the fuel cells.

The projects would be individually assessed to establish in appropriate detail the factors affecting their implementation including:

- What technology development needs to be made before the demonstration can be mounted;

- How long would this development take and what would it cost;

- Can this work be done in Canada or does it require technology transfer from outside;

- How much would the demonstration project cost and how long would it take, assuming it is mounted at a scale to generate the operating experience, confidence and credibility necessary for commercialization;

- What is the size/value of the potential market relative to the cost of the project.

The extent and success of this fuel cell development program in Canada depends fundamentally on the financial commitment that is brought to it. The lead and major obligation in this regard must be assumed by governments. The time frames are too long and the risks too great for these demonstration projects to be undertaken by private sector initiatives. The potential benefits are in the national interest and should therefore result from the renewed federal commitment to science and technology and support from other sources as appropriate.

To put the Canadian commitment to fuel cells in context it is instructive to review funding levels elsewhere. In Europe, fuel cell funding escalated after 1985 to the present level of approximately $22 million per year and is rising. In addition to already established programs in Germany and Belgium, there is renewed activity in the U.K., France and Scandinavia. Most notable new programs are in Italy $81 million over 5 years of which 83% is government funding, 17% from industry and users, and in Holland $37 million over 5 years of which 75% is government funded. By 1985, approximately $450 million was spent in the U.S. on the phosphoric acid fuel cell program, of which $100 million, or 22%, was the industry share. Present levels of spending in the U.S. are about $125 million per year, and in Japan $60 million per year.

The success of the Canadian program, benefits from or depends on a champion to represent the interests of the participating parties both individually and collectively. The Hydrogen Industry Council and its members propose to coordinate these efforts.

As a final remark we encourage all non-members of the Hydrogen Industry Council interested in our initiative to let us know of your projects and we will be glad to include your contribution and needs in the proposed program.

Thank you,

Conseil de l'industrie
de l'hydrogène
Hydrogen Industry
Council

DEVELOPMENT OF FUEL CELL APPLICATIONS IN CANADA

STATUS OF FUEL CELL TECHNOLOGIES
MARCH 1988

FUEL CELL TYPE	AFC	SPFC	PAFC	MCFC	SOFC
Operating Temperature	ambient to 120°C	ambient to limit of SPE (100°C)	200°C	550 - 700°C	1000°C
Capacity					
- Existing	up to 50 kW	up to 5 kW	up to 4.5 MW	up 10 kW	up to 5 kW
- Potential	100 - 200 kW; MW's (bipolar)	100 - 200kW	11 MW+	MW's	MW's
Electrolyte	Conc. KOH (30 - 75%)	sulfonated fluorocarbon polymer membrane, eg. - Dupont Nafion - Dow Experimental Membrane (DEM)	Conc. H_3PO_4	molten (Li,K) carbonate in Lithium aluminate matrix	stabilized zirconia
Electrodes					
- Anode	(PM's or (base metal (oxides on (carbon or (graphite	(PM's on (SPE membranes	(PM's on (teflon-(bonded (graphite	porous Ni	Co/Ni, zirconia
- Cathode				porous NiO	Sr/La manganite
Efficiency (150 mA/cm²)	60% (H_2/air)	50% (H_2/air)	45% (methane) 70% - 80% with cogeneration	55% (methane)	45% (methane)
Tolerable Feed Gas	clean H_2	clean reformate H_2+CO_2	clean reformate H_2+CO_2	natural gas (potential)	natural gas (potential)

STATUS OF FUEL CELL TECHNOLOGIES
MARCH 1988

FUEL CELL TYPE	AFC	SPFC	PAFC	MCFC	SOFC
Advantages	-low capital cost -choice of catalysts -high efficiency and power density -rapid cold-start	-rugged construction -good power density -rapid cold-start potential	-CO_2 tolerance in gas -high efficiency with co-generation -low material cost potential except catalysts	-PM's not necessary -high efficiency -good power density - internal reforming potential	-PM's not necessary -low capital potential -internal reforming potential
Disadvantages	-need pure H_2 re CO_2 contaminates electrolyte -liquid electrolyte	-high capital cost re PM's & SPE -must remove CO re PM poisoning	-PM catalyst cost -low power density -must remove CO re PM poisoning -slow cold-start	-anode de-activation/ sintering -cathode dissolution -electrolyte evaporation -corrosion -cold-start assist	-high electrolyte resistivity -component interaction -mechanical/ thermal shock -instability/ weakness -cold-start assist

STATUS OF FUEL CELL TECHNOLOGIES
MARCH 1988

FUEL CELL TYPE	AFC	SPFC	PAFC	MCFC	SOFC
Participants					
U.S.	IFC, NASA-Lewis	IFC, Los Alamos, ERC	IFC, Westinghouse, ERC, Engelhard	IFC, ERC, GE, IGT (M-C Power)	Westinghouse ("tubular") Argonne ("monolithic")
Japan	Moonlight Project terminated '84		Mitsubishi, Fuji, Hitachi, Toshiba, Sanyo	Mitsubishi, Hitachi, Fuji, Toshiba	Moonlight Project terminated '86
Europe	Elenco, Siemens		Cise	ESTS - Hoogoevens ENEA - FARE	
Canada	Astris, U of T	Ballard	Hydro-Quebec, B.C. Hydro Ontario Hydro		

FUEL CELL APPLICATION OPPORTUNITIES

MARKET SEGMENT	TYPICAL SYSTEM SIZE	MARKET SIZE, MW	INFORMATION SOURCE *	PREFERRED FUEL	COMPETITIVE ADVANTAGE	FEASIBILITY IN CANADA 1 - 10	ADVANTAGE IN CANADA 1 - 10	TOTAL MERIT POINTS 1 - 20
Spacecraft	1 - 50 kW	1	8	H_2/O_2	Compactness, energy/weight ratio, Source of drinking water	5	7	12
Energy Systems								
Electric Utility	1 - 20 MW	17,500(US) 2,000 (ONT)	3 13	NG OIL COAL	Short construction time, Modularity Expandability, Distributed power generation, Clean operation in urban areas	2	5	7
Cogeneration, Commercial and Residential Buildings	25 - 1000 kW	18,000 (US) 4,000 (ONT) 412 (BC)	2,5,7 13 11	NG	Use of by-product heat, Lowering peak demand	6	7	13
Northern Ontario Communities	0.1 - 1.2 MW	10	13	OIL,LNG H_2	Use of by-product heat, Better fuel utilization	6	9	15
Remote communities in Québec	0.1 - 1 MW	100	12	OIL/LNG H_2	Ditto	6	9	15

* Information Source Key:

1. Arthur D. Little
2. Department of Energy (U.S.)
3. EPRI
4. Fuel Cell Applications Group
5. Gas Reasearch Institute
6. Jarvis Clark
7. Industrial Fuel Cell Association (IFCA)
8. NASA
9. Occidental Chemical Corporation
10. Volvo Corporation
11. B.C. Hydro
12. Hydro-Québec
13. Ontario Hydro
14. Canadian National Railways
15. Author's estimate

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MARKET SEGMENT	TYPICAL SYSTEM SIZE	MARKET SIZE, MW	INFORMATION SOURCE *	PREFERRED FUEL	COMPETITIVE ADVANTAGE	FEASIBILITY IN CANADA 1 - 10	ADVANTAGE IN CANADA 1 - 10	TOTAL MERIT POINTS 1 - 20
Industrial Generation/Cogeneration								
Chloralkali/chlorate	0.5 - 10 MW	2,975 (US) 300 (CAN)	1,9 15	H_2	Utilization of by-product H_2, Lowering electricity demand	7	7	14
Petrochemical	5 MW	4,500 (US) 172 (BC)	1 11	H_2, HC	Ditto	4	7	11
Petroleum Refining	5 MW	12,000 (US) 36 (BC)	1 11	H_2, HC	Ditto	4	7	11
Resource Industries: Underground Mining	20 - 500 KW	500 (CAN)	4,6	H_2	Low pollution underground, Low noise, Low waste heat, Elimination of 600V grid	8	8	16
Wood Product Mills	1 MW	164 (BC)	11	NG	By-product heat Cost	6	8	14
Pulp and Paper Mills	5 MW	252 (BC)	11	NG	Ditto	4	8	12
Metal Mills (aluminum)	5 MW	93 (BC)	11	NG	Ditto	4	8	12
Other Industries: Malt Beverage, Food	500 kW	65 (BC)	11	NG	Ditto	6	8	14

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FUEL CELL APPLICATION OPPORTUNITIES

MARKET SEGMENT	TYPICAL SYSTEM SIZE	MARKET SIZE, MW	INFORMATION SOURCE *	PREFERRED FUEL	COMPETITIVE ADVANTAGE	FEASIBILITY IN CANADA 1 - 10	ADVANTAGE IN CANADA 1 - 10	TOTAL MERIT POINTS 1 - 20
Commercial & Military								
Stationary Generators Military, Coast Guard, Remote Site - Weather, Communications Backup Power - Computer, Communications Emergency Power - Mines etc.	0.5 - 500 kW	10,000	15	NG, Me H_2, LNG	Fast start, Low noise and emissions	7	7	14
Portable Generators	0.1 - 7 kW	15,200	10	Me, H_2 LNG	Self-starting, Instant start, Clean and quiet operation	8	7	15
Consumer Products for outdoors, RV's, cottages, households education, hobbies	0.1 - 5 kW	open		Me, H_2	Operational characteristics unattainable with batteries or internal combustion engine			

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FUEL CELL APPLICATION OPPORTUNITIES

MARKET SEGMENT	TYPICAL SYSTEM SIZE	MARKET SIZE, MW	INFORMATION SOURCE *	PREFERRED FUEL	COMPETITIVE ADVANTAGE	FEASIBILITY IN CANADA 1 - 10	ADVANTAGE IN CANADA 1 - 10	TOTAL MERIT POINTS 1 - 20
Transportation								
Railway Locomotive	2.5 MW	48,000 (US) 7,500 (CAN)	1 14	H_2, LNG Me, OIL	"Electrification via fuel cell, Elimination of need for overhead catenary	5	9	14
Ships	1 - 5 MW			H_2, LNG, Me		5	5	10
Submarines, small submersibles	10 - 750 kW	0.2 (CAN)	4	H_2/O_2	No exhaust-full submerged operation on hydrogen	7	8	15
Heavy trucks, Buses	260 kW	36,400 (CAN)	4	Me, H_2	Environmentally clean, Efficient-better mileage	5	7	12
Vans & automobiles	10 - 40 kW	175,000 (CAN)	4	Me	Ditto	2	7	9
Specialized vehicles - forklift trucks - golfcarts - wheelchairs - etc.	1 - 10 kW	6,000	15	Me, H_2	Clean and efficient Possible indoor operation, Lower cost and better operational characteristics than on batteries	8	6	14
Resources Industries								
Underground Mining								

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15. Author's estimate

RATIONALE

- Inherent environmental advantages
- Competitive position of Canada
- Likelihood of increasing conventional fuel prices

DEVELOPMENT & DEMONSTRATION PROJECTS

DEMONSTRATION PROJECT			FUEL CELL		COMPETITIVE COST		TIME FRAME YEARS		MARKET POTENTIAL		
#	TITLE	FUEL	SIZE KW	TYPE	CAPITAL $/kW	OPERATING $/kWh	TECHNOLOGY DEVELOPMENT	DEMON-STRATION	MW	$x10^6	INTEREST RATING
1.	Portable Field Generator, military	Me	1-4	SPFC	5000		2-5	3-5	4	20	19
2.	Portable Generator, Commercial	H_2 Me	1-10	AFC SPFC	1500		0-3	2	760	1140	21
3.	Powerplant for specialized vehicles	H_2 Me	1-10	AFC SPFC	1000		1-3	3	300	300	20
4.	Powerplant for submersibles	H_2/O_2	2-20	AFC SPFC	10000		1	3	0.2	2	18
5.	Generator for use in space	H_2/O_2	3-10	AFC SPFC	30000		3	5	0.1	3	14
6.	Stationary Generators	H_2,Me NG, LNG	10-500	AFC	500	0.12	3	3	500	250	19
7.	Powerplant for cars, vans	Me, LNG	10-40	SPFC AFC	150		2-5	2-3	17500	2625	13
8.	Powerplant for underground mining	H_2/O_2	20-500	AFC	600	0.30	0-2	2-3	500	300	20
9.	Powerplant for trucks, buses	Me, H_2	250	AFC SPFC PAFC	300		2-3	2-3	3640	1092	17

DEVELOPMENT & DEMONSTRATION PROJECTS

DEMONSTRATION PROJECT		FUEL CELL			COMPETITIVE COST		TIME FRAME YEARS		MARKET POTENTIAL		
#	TITLE	FUEL	SIZE KW	TYPE	CAPITAL $/kW	OPERATING $/kWh	TECHNOLOGY DEVELOPMENT	DEMON-STRATION	MW	$x10^6	INTEREST RATING
10.	Cogeneration Powerplant	NG	25-1000	PAFC	1500	0.04			4400	6600	19
11.	Powerplant for remote communities	OIL LNG H_2	0.1-1MW	MCFC PAFC AFC	1500	0.30	3-5	2-4	110	165	21
12.	Cogeneration in chloralkali plants	H_2	0.5-10MW	AFC	500	0.04	2-3	3-7	300	150	16
13.	Powerplant for railway locomotive	H_2 Me LNG	2.5 MW	AFC PAFC MCFC	1000		6	5-8	7500	7500	18
14.	Utility Powerplant	NG COAL	10 MW	MCFC PACF	1000	0.04	8	5-7	3000	3000	10

IMPLEMENTING FACTORS

- Technology development required
- Length and cost of development
- Work done in Canada or technology transfer required
- Length and cost of demonstration project
- Size/value of potential market

FUEL CELL FUNDING

COUNTRY	TIME FRAME	FUNDING ($MM)	INDUSTRY SHARE	GOV'T SHARE
US (PAFC)	to 1985	$450	22%	78%
US	present	$125/yr	-	-
JAPAN	present	$60/yr	-	-
EUROPE	present	$22/yr	-	-
ITALY	5 yrs	$81	17%	83%
HOLLAND	5 yrs	$37	25%	75%

Synopsis of Workshop

C. A. Ward and R. D. Venter
Thermodynamics and Kinetics Laboratory
Department of Mechanical Engineering
University of Toronto

At the commencement of this Workshop, Mr. R. Greven of the Ontario Ministry of Energy identified three specific questions for consideration by the attendees. The questions were: 1) What - if anything - should the Canadian and Ontario Governments be doing to support the development and commercialization of fuel cells? 2) Will government participation significantly advance this commercialization? 3) Can Canadian companies profit from fuel cells? Although none of the speakers addressed these questions directly, tentative answers did emerge from the presentations and discussions, but the answers were not uniform for all types of fuel cells.

Indeed, fuel cells can not be reasonably examined by lumping them all together and The Ministry's questions must be understood as being directed at any type of fuel cell. In the Workshop, fuel cells were categorized in two ways. One way was according to the electrolyte used. The particular electrolyte chosen for a fuel cell is in large measure determined by the source from which hydrogen is to be derived. For example, the phosphoric acid fuel cell was designed to draw its hydrogen from reformed natural gas or a light hydrocarbon, its economic advantage from its higher efficiency as compared to more conventional methods of producing power and its environmental advantage from the low emission of NO_x and SO_2. Whereas the molten carbonate fuel cells are being designed to operate on a hydrogen stream that is drawn from reformed coal. The advantage of the molten carbonate fuel cells are envisioned as arising from the low price of their primary fuel (coal), the abundance of this fuel in North America and the higher efficiency with which these fuel cells convert the hydrogen derived from coal into electricity. The phosphoric

acid and the molten carbonate fuel cells are both directed at major power generation requirements, i.e. megawatt sized units.

The second way in which the fuel cells were classified was according to their power generating capacity. For power production of a few kilowatts or less, other fuel cells are also being developed. These include the solid polymer, the potassium hydro-oxide (KOH) or alkaline, smaller versions of the phosphoric acid cells and the solid oxide fuel cell. The applications envisioned for this group of fuel cells are in transportation, certain industrial applications and co-generation applications where both the electricity and heating available from the fuel cells can be used. The classification in terms of size can not be thought of as rigid. In principle, any one of the fuel cell systems can be built to larger sizes. However, there are lower limits beyond which it does not make economic sense to proceed. For example, the phosphoric acid system with its reformer is probably not a reasonable option for applications of less than a few kilowatts.

FUEL CELLS FOR MAJOR POWER GENERATION

Fuel cells are not penetrating the market at the rate at which it might have been expected; the reason for this is that the "cost-benefit" analyses being performed do not indicate their clear advantage over other means of generating electrical power. However, it is important to note that one of the major "benefits" of fuel cells is not being accorded the weight that is deserved from the point of view of society as a whole. This "benefit" is the fact that the fuel cell is a potentially environmentally benign method for generating electrical power. As long as the polluting effects of power produced from coal, for example, are not thought as a major "cost" in the analysis, the fuel cell "cost" is greater than that of conventional methods for power generation. Although for a substantial period of time, the Electric Power Research Institute has funded investigations directed at applying fuel cells for electric power generation, they have been unable to convince the utilities of the benefit

of mounting a demonstration of an 11 MW sized unit. No doubt this is a sound economic decision based on the present definitions of the economic parameters. The question was raised at the Workshop of whether the present definitions properly include the cost of pollution as a cost of power generation. However, only governments can bring this "cost" into the equation and whether this can be done by one level of government or even by the government of one country is not clear.

FUEL CELLS IN TRANSPORTATION

Traditionally, the application of fuel cells for automobiles has been viewed as one of the most difficult areas for fuel cells to penetrate because of the on-board hydrogen storage problem; however, the possibility of using methanol as the fuel could solve the storage problem. Especially if the direct conversion of methanol in an appropriate fuel cell could be accomplished. One possibility is the solid-oxide fuel cell that has been identified as having attractive characteristics. Another possibility is the development of a suitable electrocatalyst for the direct electro-oxidation of methanol. However, both of these possibilities require considerable development. It was suggested that unless this development is driven by an impending environmental catastrophe, or a fuel shortage, they are unlikely to attract the necessary funding.

There are certain transportation applications where local environmental considerations can not be ignored. One of these is where the vehicle must operate within a confined space, such as fork-lift trucks in warehouses, mining vehicles, or the golf carts used to transport passengers in large airports (e.g. Dallas-Fort Worth).

In the case of fork-lift trucks, Mr. F. W. Spillers of the Fuel Cell Association pointed out that a trend toward electrically powered vehicles could be identified, that there are some 350,000 such vehicles produced each year and that about one-third of the total are presently electrically powered. Under circumstances where the

truck must operate for three shifts, there are logistical problems with using batteries (e.g. the time required to recharge a battery necessitates that multiple batteries be available, and multiple charging units as well). In this circumstance, it would appear that fuel cells may compete very well with batteries and that this might very well be a "near-term" opportunity for fuel cells to enter the market.

DEMONSTRATION PROJECTS FOR FUEL CELLS

A number of speakers emphasized the importance of demonstration projects. One such project is proceeding at B.C. Hydro in which a 40 kW phosphoric acid fuel cell is being tested. The performance to-date has been close to that claimed by the manufacturer. It is important to realize that a fuel cell power system has been built that meets its projected performance goals, including its capacity to generate significant power with low pollution. The economic climate in which the phosphoric acid fuel cell was designed (mid-seventies) has significantly changed and the slowdown in the further development of this type of fuel cell must be seen in that context.

As pointed out by Mr. Prater and Mr. Howard of Ballard Technologies Corporation, there have been significant advances in fuel cell technology since that time. For example, by using a Dow membrane as the electrolyte in the Ballard fuel cell system, they have projected that as a result of the improved performance achieved with this membrane the fuel cell stack required to produce 40 kW would occupy only 0.11 m^3 (4 $ft.^3$). This amounts to a significant reduction in size, and it opens the possibility of fuel cells being used in new applications.

SUMMARY

To summarize then, the answers that emerged from the Workshop to the questions raised by Mr. Greven would seem to be the following:

1. What - if anything - should the Canadian and Ontario governments be doing to support the development and commercialization of fuel cells?

Basically there are two things:

a. A number of carefully chosen demonstration projects that were directed at establishing the performance of fuel cells would be of great benefit. These application areas should be in either transportation (but not automobiles), or perhaps in electric power generation. They could be selected in areas where fuel cells would compete with batteries (such as in some fork-lift trucks) or for applications such as the power system of vehicles where the higher efficiency of fuel cells is of principal importance and where the fuel storage problem is not too great a penalty. A second transportation application might be in locomotives. In private discussions at the Workshop, it was pointed out that fuel cell powered locomotives could be an attractive way to electrify Canadian railways. The fuel, hydrogen, could be generated from nuclear power and when used with on-board fuel cells the high capital cost of overhead electrical supply lines would be avoided.

A demonstration in which fuel cells are integrated with the nuclear power system for load levelling should be considered. The long-term goal of this demonstration would be the elimination of power generation from fossil fuels. This demonstration could be of particular advantage if point b (see below) is acted upon.

Since a number of different fuel cells could be developed for these applications, it would be appropriate to select more than one type in the initial stages and then after comparing their relative performance, costs, and operating characteristics, select one for the final demonstration in each area.

b. Governments should recognize the damage done to the environment when power is generated from fossil fuels, and insure that this cost is taken into account in comparing different methods of generating power. For example, the pollution characteristics of the BC hydro operated phosphoric acid fuel cell should be compared with that of generating 40 kW of power from the coal fired plants that are used in Ontario.

2. Will the government significantly advance this commercialization? Since fuel cells represent a potential method for generating power while doing a minimum of damage to the environment, and they are unique in that regard, it is appropriate for governments (at both the Federal and Provincial levels) to be involved. Only governments can assess the "cost" of environment damage done by the different power generating methods and only they can ensure that this cost is part of the assessment for all methods of generating power. If the environmental cost of generating power were assessed, it could greatly promote the prospects for commercialization of fuel cells.

3. Can Canadian companies profit from fuel cells? Canada is particularly well positioned to integrate fuel cells into the mix of power production systems because of the nuclear power system and the James Bay project. Both of these represent the possibilities of economically generating electrical power, a portion of which could

be used to generate hydrogen. The hydrogen could then be used by fuel cells. If Canadian companies entered this program for changing the emphasis from fossil fuel based power production to nuclear and hydro-electric, there is no reason to believe they could not benefit greatly. However, before this enterprise is commercially feasible, significant work must be done by Governments on the points raised in response to questions 1) and 2) above.

FUEL CELLS WORKSHOP
April 28, 1988

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